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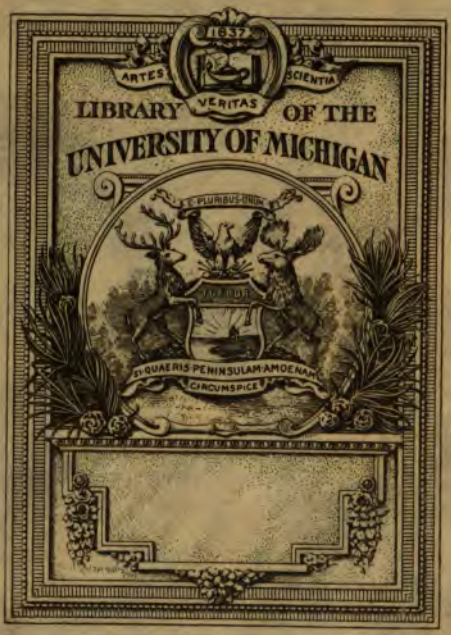
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ASTRONOMY FOR AMATEURS

IN PREPARATION.

CELESTIAL PHYSICS:

A PRACTICAL MANUAL OF

ASTRONOMICAL SPECTROSCOPY AND PHOTOGRAPHY

FOR MODERATE INSTRUMENTS.

EDITED BY

JOHN A. WESTWOOD OLIVER,

With the assistance of Eminent Authorities.

31913

ASTRONOMY FOR AMATEURS

A PRACTICAL MANUAL

OF

TELESCOPIC RESEARCH

IN ALL LATITUDES

ADAPTED TO THE POWERS OF MODERATE INSTRUMENTS

EDITED BY

JOHN A. WESTWOOD OLIVER

WITH THE ASSISTANCE OF

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PREFACE.

THE aim of this volume is entirely practical. Its pages are intended to afford the amateur astronomer, possessed of limited instrumental means but yet anxious to devote his labours to the furtherance of astronomical science, such hints and suggestions as will help him to direct his efforts into the channels which experience has indicated as best fitted to his qualifications and equipment.

The amount of valuable work in astronomy that can be efficiently done by amateurs is not inconsiderable, as a glance at the history of the science will show. It is true that the size and excellence of the telescopes in public observatories has of recent years been steadily increasing, the disparity between the magnificent instrument in the Lick Observatory and a 'common' telescope of twenty years ago being almost ludicrous; but then the quality and power of the instruments in the hands of amateurs has been gradually improving also, and there is no reason to doubt that within their respective spheres the professional and amateur astronomers, so far as equipment is concerned, have undergone development about equally. By the amateurs, more-

over, through their augmented numbers, has been secured the great advantage of the co-operative method of research. On the whole, there is good ground for the hope that amateur effort will take quite as prominent and important a place in the future of astronomy as it has done in the past.

But one thing is essential. For successful results to be obtained with small or moderate instruments, it is absolutely necessary that the work be selected with strict regard to the powers of the tool and the capabilities of the worker. The end must be carefully adapted to the means, since it is the privilege of few observers to adapt their means to any chosen end. The possessor of a three-inch telescope will toil to no good purpose in the field of double stars, as a man with deficient colour sense will only attain worthless results in stellar chromatics. Such wise selection will be materially aided, I trust, by the perusal of the pages which follow.

The scope of the volume, it need scarcely be remarked, has been limited to astronomical work (as distinguished from desultory star-gazing for recreation or amusement) suitable to the capacity of amateurs (as distinguished from professional observers stationed in fully-equipped observatories). It is meant to fill, therefore, a place of its own in astronomical literature. The young telescopist in search of the beauties of the firmament should begin with Proctor's 'Half-hours with the Stars,' or Captain Noble's 'Hours with a Three-inch Telescope,' and later on get Webb's invaluable 'Celestial Objects for Common Telescopes.'

My own share in the preparation of the book has been for the most part editorial. From its nature it must needs be many-authored, since practical hints, to be of any real use,

must come from specialists, and few men are specialists in more than one branch of astronomy. Without the assistance of my able coadjutors the scheme could never have got beyond its inception; and I take this opportunity of publicly thanking them for their ready co-operation, to which alone is due such value as the work may possess.

And in addition to the contributors whose names appear on the title-page, I have to acknowledge my obligation to many eminent observers for valuable suggestions offered while the work was in progress, as well as for material which has been incorporated. In this regard my thanks are due to the Rev. S. J. Perry, D.Sc., F.R.S., of Stonyhurst Observatory; Dr. Ralph Copeland, F.R.A.S., of Lord Crawford's Observatory, Dun Echt; Prof. Edward C. Pickering, of Harvard College Observatory, Cambridge, U.S.; Mr. Arthur Searle, of the same institution; Mr. Lewis Swift, of the Warner Observatory, Rochester, N.Y.; Rev. S. J. Johnson, F.R.A.S., Mr. B. J. Hopkins, F.R.A.S., Mr. Kenneth J. Tarrant, Mr. S. Maitland Baird Gemmill, Mr. F. W. Levander, F.R.A.S., and Mr. T. R. Clapham.

It is to be hoped, should an opportunity of revising the work ever present itself, that this list will be largely augmented. In matters of astronomical practice the collation of the widest possible experience is desirable. Further suggestions are therefore invited.

J. A. WESTWOOD OLIVER.

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ASTRONOMY FOR AMATEURS.

CHAPTER I.

PRELIMINARY.

Amateur Astronomers.—Astronomical science owes much, and particularly in climates such as that of England must always continue to owe much, to the work of amateurs. By the term amateurs here is meant observers with more or less limited equipment rather than persons who do not make astronomy their pursuit. If an observer were to follow other avocations during the day and work in a large public observatory at night, he would not be, astronomically speaking, an amateur any more than one who devotes himself exclusively to peering through a 3-inch telescope is a professional. Instrumental qualification is the main point of distinction—a distinction which it is necessary thus to enlarge upon because the term amateur is used to define the scope of the present work. The degree of system attainable in the observations is another point. With the professional observer astronomy comes first; with the amateur, it may have to come after a great many things; and consequently researches of a rigorous and systematic character are possible to the one which may be

totally impracticable to the other. It is not necessary, however, for us to arrive at a hard and fast definition of what constitutes an amateur. For our present purpose he may vary, both as regards the amount of time at his disposal and the instruments at his command, within very wide limits. He may be only able to spare an hour or two a week to astronomical work, or he may have nothing else to do; he may have a fine telescope, a very ordinary one, or even no telescope at all. We simply assume that he has not the advantage of working in one of the large and fully-equipped observatories, with all the personal qualifications of the trained and experienced astronomer. If he fall anywhere outside that category, the chapters which follow are intended to meet his wants.

Working Amateurs.—It may be taken for granted that the majority of beginners in astronomy purchase a telescope merely with a view to finding in its use an intellectual recreation for leisure hours. Very few set out with the avowed intention of employing it in serious work. Under these circumstances we cannot reasonably expect them to make their observations with much regard to system or with any definite object beyond that of amusing themselves. They range through the heavens for whatever is most striking or interesting, and, having exhausted the curiosities of the firmament, turn away, perhaps, to the scrutiny of some other collection of Nature's wonders. Some few, however, if they receive encouragement at the right moment, instead of abandoning the astronomical field when they have sufficiently gratified their curiosity, become possessed by a new enthusiasm, and begin to consider if it is not possible for them so to direct their labours as to contribute, however humbly, to the advancement of the science.

They may readily assure themselves that they can do

so, and further, that their help need not be of a halting and half-satisfactory kind, but most efficient and valuable. The fields of work that lie open to amateur effort are numerous and inexhaustible. Some of them, moreover, are more likely to respond to the efforts of the amateur than to those of the professional observer.

When the telescopist has reached this conclusion, it becomes of the first importance that he should be wisely advised in his selection of a line of work. For if he adopt, in his ignorance, a research that is above his powers he will soon be beset by harassing difficulties, lose heart, and end in disappointment and failure; while if he is so advised as to choose one well within his capacity, its pursuit will rapidly acquire interest with the consciousness of progress, encouragement will be found in the favourable comparison which his work bears with that of others in the same department, and the satisfaction of contributing something of real value to the stock of human knowledge will kindle an ardour that may safely be trusted to carry him onward along the laborious path of scientific investigation. It is not our function to dictate what particular line should be followed in each individual case. We can only counsel each aspirant to try to ascertain his natural bent, and, taking that into consideration with the time and means at his disposal, select whichever department of work seems best to fall in with these conditions.

One further point here. Having chosen a suitable line of work, it is absolutely essential to success that the worker concentrate his attention upon it, as closely at least as circumstances will allow. It is very pleasant to flit gaily about among the celestial orbs, spending a night or two with the moon and then betaking ourselves to a planet or a distant nebula for a change, but such desultory

observation seldom leads to scientific results, unless by accident, and the observer cannot in any sense be said to be doing work. Individuals, we have said, manifest special aptitudes in astronomical as in other kinds of work, and it is well, as a preliminary, to find out in what direction one's aptitude lies; but, having once found it, let the appropriate branch of investigation be followed without swerving. It *must* lead to something. When Schwabe began to make daily observations of the spots on the sun he had not the slightest inkling of a discovery. He persevered for thirty years, in blind faith part of the time, making in all some 9,000 observations; and his reward did not fail him. He discovered and demonstrated the eleven-year cycle.

Available Fields for Work.—If we take a comprehensive glance at the history of modern astronomy, we must perceive that further progress is to be looked for in two directions, neither of them the one in which the most enormous strides have been made in the past. It would be rash to say that the utmost limit of the telescope as a space-penetrator has been reached, or even closely approached, nor can we go so far as to affirm that the exploration of the boundless realms of space is an exhausted field of astronomical work; but we think it is plain that the mere discovery, by means of the telescope, of new celestial objects, for long so abundantly fruitful a branch of research, is rapidly getting more and more difficult of accomplishment, and each fresh conquest is becoming less and less worth the time and labour and ingenuity in overcoming physical obstacles that must of necessity be spent in effecting it. Some of the earlier telescopists accomplished an amount of work in the way of exploring the starry heavens that no score of observers to-day can together hope to rival; and while it is well that a few

workers should still find their congenial sphere in the further pursuit of the same investigation, the majority must naturally turn with zest to any new departure that seems to hold out fair promise of valuable results. Such lines of departure, not by any means new, but so wide and far-reaching as to be yet little more than opened up, are, the close and persistent scrutiny of individual objects or of particular classes of objects in the heavens (in other words, the specialisation of astronomical work), and the application and development of the new methods of research made available by the progress of physical science—namely, spectroscopy and photography.

And it so happens, very fortunately, that the former departure at least is well within the reach of the amateur.[1] In all researches requiring frequent, and (as far as may be) uninterrupted observations, the amateur with his moderate instrument has a distinct advantage over his professional brother, the difficulty of obtaining good definition with high powers (at any rate in England) rendering the large telescopes useless for the sustained study of any object. Moreover, if amateurs are in sufficient numbers to organise their work, they then become, to a certain extent, independent of weather conditions altogether, and secure a degree of continuity in their results only attainable in most exceptionally favoured situations.

It is not necessary, in this chapter, to do much more than enumerate the departments of work that invite the attention of the amateur; but a brief summary may serve a useful purpose by exhibiting at a glance the special qualifications required in each case.

[1] A manual of work in Astronomical Physics (Spectroscopy and Photography), similar in scope and arrangement to the present volume, is in contemplation.

1. *Solar Work.*—The observation of solar phenomena offers one conspicuous advantage over all other branches of astronomical work—it does not interfere with the night's rest. It is an equivocal advantage, however, to many—perhaps most—amateurs, who have other pursuits to attend to in the day-time. To those who are fully occupied during the ordinary working day, it is, indeed, an absolutely inaccessible field in the winter season, and even in summer is only accessible under unfavourable conditions, the morning or evening sun being too near the horizon for really good work to be possible. But given the requisite opportunity, no object in the heavens presents a more pleasingly varied and fruitful field of research. The available work for the telescope alone is limited to the examination of the sun's surface, the most important feature of which is the spots. The study of spot changes and groupings may be very efficiently carried on with small telescopic power; but a great difficulty with this work, so far as the amateur is concerned, is that continuity is a very important factor in the value of the results. Unless, therefore, a good deal of time can be devoted to the work, it should scarcely be attempted. The close examination and detailed delineation of individual spots is not open to the same objection, and may be undertaken by the most intermittent observer.

2. *Lunar Work.*—The study of lunar detail is such an obvious field for the exercise of moderate instruments that we need do no more than mention it.

3. *Planetary Work.*—Much controversy has raged over the capabilities of small telescopes in defining the planetary markings. Whatever view we take of the matter, there is unquestionably sufficient work for moderate instruments to render this department well worthy the attention of

the amateur. Mars, when favourably situated, will repay close scrutiny, and Jupiter is always an object of interest. To study the changes on the latter to any purpose, the observations must be fairly continuous.

4. *Comet seeking* is an excessively tedious pursuit, the prime qualification for which is perseverance. Systematic search, in co-operation with other workers, holds out the best prospect of success.

5. *Double Stars.*—In a general way the amateur is to be deterred from undertaking this work, rather than encouraged. It requires a telescope of such power and quality as distinctly raise it out of the category 'common.' An enormous amount of valuable time has been wasted in silly wrangling over the alleged achievements of telescopes in splitting pairs just verging on the limit of their powers. Such feats being due to an abnormal condition of the atmosphere, or of the imagination, seldom admit of proof by repetition, and even if clearly substantiated serve no useful purpose.

6. *Variable Stars.*—Considerable telescopic power is required for some of these objects, but the more important of them may be efficiently observed with a good opera-glass. The observer may devote himself either to the study of known or suspected variables (of which there are many hundreds), with a view to the better determination of their period and degree of variation, or to the search for entirely new objects of the kind—preferably to the former work. Systematic observation is so particularly desirable here, that the amateur should not fail to give his support to any scheme for the organisation of the work that may be within his reach. The appearance of temporary stars occasionally affords a pleasing relief to the monotony of the study of variables proper.

7. *Star Colours.*—In the study of star colours we have a hitherto somewhat neglected field. The instrumental equipment may vary within very wide limits, but it is important that the observer should have no marked idiosyncrasy of vision. Long practice is necessary before the eye becomes apt in the discrimination of fine gradations of tint. The work, however, is interesting.

8. *Stellar Distribution.*—The same remark as to equipment applies to the work of making star-surveys. Surveys with all sizes of instruments are wanted. Even one with spectacles would lead to valuable results. But they must be thorough if they are to be of any use at all, and thoroughness implies long and arduous labour. In attempting to make delineations of the galaxy, education of the eye is highly important.

9. *The Zodiacal Light* does not require any instruments for its general observation, although they may be used with advantage in making exact determinations of its position. The opportunities of studying this phenomenon, under favourable conditions, are rare.

10. *Meteors* present the only branch of astronomical research in which really efficient work can be done with the naked eye. As falling stars appear every night the sky is clear, and the moon not very bright, observations may be carried on constantly.

11. *Auroræ.*—The observation of auroræ belongs properly to the domain of meteorology, but with the sanction of frequent usage we include the subject here. In England the opportunities of witnessing the phenomenon are not of very common occurrence, and, as special instruments and considerable experience must be possessed before observations of much value can be made, it is doubtful if the work will ever become popular with amateurs. This

refers more particularly to the study of the external features of the phenomenon, and of its accompanying meteorological conditions. With the spectroscopic branch of the research it is otherwise, but that falls outside the scope of the present volume. It need hardly be said that amateurs resident in higher latitudes, where the aurora is a frequent or nightly apparition, or having occasion to sojourn far enough south for the aurora australis to be seen, should not fail to turn their exceptional opportunities to account by making a special study of the phenomenon.

Amateur Work in England.—It has been remarked that, notwithstanding the increasing popular interest in astronomical science, the improved construction and reduced price of telescopes, and the consequent increment of observing power throughout the country, the valuable contributions by English amateurs to astronomy are on the decrease. When Denning discovered one of the seven comets which appeared in 1881, it was the first discovery of the kind made in England for a quarter of a century. That the country of Halley, the father of cometic astronomy, should fall so far behind, is sad indeed. The cause of this decadence is doubtless to be found in the changed conditions of astronomical research. The establishment of splendidly equipped observatories in regions favoured with clearer skies has been going on apace. Look, for example, at the Lick Observatory on Mount Hamilton (Cal.). Elevated above the usual stratum of cloud formation, the number of clear nights in the year is something like three hundred more or less. The steadiness of the atmosphere far exceeds even the most sanguine expectations of astronomers. In the construction of the instrument, every improvement which experience suggests has been adopted, regardless of money cost. The great telescope

will magnify—when the maximum power is employed, and the atmospheric conditions will admit of its employment on at least a few nights in the year—about 3,500 diameters, bringing such an object as the moon (theoretically) within a distance of sixty miles, and enabling the observer under favourable conditions of illumination to make out details on the lunar surface of no greater size than some of the larger edifices on the earth. It is obvious that for work requiring high magnifying power, and all but absolute precision of measurement, observatories of this kind must practically monopolise the field. Amateurs with their common instruments and unfavourable surroundings cannot contest it. And as lavishly equipped mountain observatories increase in number, the chances of the English amateur, so far as certain researches are concerned, become more and more remote. The progress of astronomical knowledge is at present hindered not so much by instrumental imperfections as by meteorological conditions, and when these hindering conditions can be so largely escaped elsewhere, it is inevitable that a country where the climate is a by-word and a reproach should fall out of the running.

Discouraging though this conclusion may seem, there is yet hope for the amateur in it. We cannot, with our murky skies, retain our leading place as universe explorers. Supremacy is now determined by the weather more than by anything else, knowledge and intellectual vigour being no longer the monopoly of Europe. But, as we have already said, this extremity is the amateur's opportunity. Astronomy has not been, and never will be, furthered by large telescopes alone. There is ample work for the small ones as well. Perhaps it is not too much to say that the telescope of reasonably good workmanship does not exist that is incapable of becoming immortalised in

the page of astronomical history, if properly employed. Everything, however, depends on that—its proper employment. In so far as the amateur confines himself to the best use of his available means, precisely to that extent will he be successful. Adaptation of the end to the means is the golden rule of astronomical work. There is no merit in endeavouring to make an instrument transcend its powers, or in trying to surpass one's opportunities. A small telescope may be made to resolve a difficult pair, or a diligent observer may be clever enough to recognise Venus through the shimmer of countless chimneys. The achievement is curious, but it is wholly profitless.

We must stoop to conquer. The further exploration of the stellar universe is the work of great telescopes. It is for the smaller ones to follow and investigate, by close, sustained, persistent scrutiny, the infinite detail of the nearer orbs. And in this work English amateurs are bearing, and will surely always bear, an honourable part.

Amateurs Abroad.—It is unfortunate for astronomy that the enthusiasm which inspires English amateurs does not yet extend to the colonies. Australia is favoured in the matter of 'observing' weather beyond most countries in the world; its cloudless skies would seem to the English observer an astronomical paradise; but in the meantime the telescopes to take advantage of these rare conditions are few and far between. Colonial life, no doubt, is not conducive to a pursuit that makes considerable demands upon one's time, but the fault lies nearly as much with the authors of astronomical manuals, who are in the habit (or were so until very recently) of leaving the southern skies as completely out of account as if the other hemisphere did not exist. It is hoped that the astronomical worker, whether in Australia or America, India or Africa,

will derive the same benefit from this book as the worker in England, or frequently more, since natural advantages may enable him to prosecute with ease and success a line of research which in England would only lead to vexation of spirit. England is, and perhaps always will be, *par excellence* the home of small telescopes, since the climatic conditions discount the employment of large ones, but that does not mean that small instruments are to be despised elsewhere. A good telescope, however small, in efficient hands is capable of useful work all the world over.

FACTORS OF ERROR.—So long as the telescopist is bent only on his personal amusement, it is not of much consequence whether he sees the celestial objects as they really are or not; but when he undertakes serious work, it becomes of the very first importance that he take every precaution, and spare no pains to reduce the chances of error. Astronomical research is one long struggle with the disabilities of our physical conditions. To reach our eyes the light of the starry host must pass through the atmosphere, with what absolute result we do not know, although we do know that the degree of distortion due to this circumstance varies within sufficiently wide limits to constitute an important element in any observation. Then having reached our eyes, the image becomes the sport of our physiological idiosyncrasies, again with what absolute result we do not know, although comparison discloses divergencies almost startling, not only between the observations of individuals, but between the observations of the same individual at different times. Finally, to magnify the planetary image, or to collect and focus the feeble glimmer of the star, we employ the telescope; and in so doing we directly introduce a new source of derangement and uncertainty. Between the atmospheric, the personal, and the

instrumental factors of error, the path of the truth-seeking astronomer is far from an easy one.

Experience and long practice enable the observer to avoid the risk of all flagrant error, while, for work involving delicate measurements, mathematical methods of correction have been devised.[1] But the beginner has neither experience to guide him nor practice to help him, and therefore his only resource under the circumstances is the utmost *wariness*. Always to be on the alert for error, particularly when the result of an observation differs from that of previous observations or the observations of others (and holds out the promise, therefore, of a new discovery), is the first essential of the successful worker. Better leave the record of a unique observation unannounced, if there be the slightest doubt about it, than set scores of busy eyes watching and working only to prove a negative, and run the risk of establishing a reputation (which will be but slowly outlived) for untrustworthiness.

ORGANIZATION.—One immediate consequence of our uncertain and locally variable climate, is an especial necessity for some plan of co-operation among observers, whereby the drawbacks under which they labour may, in a measure, be obviated. When a thick cloud pall is stretched over the face of the sky in one neighbourhood, it by no means follows that all parts of the country are similarly circumstanced. On the contrary, it is exceptional for a cloud bank to be so extensive as to cover the whole area of the British Isles at the same time, unbroken and without a rift.

[1] The site of the Lick Observatory is so much nearer perfection as regards atmospheric conditions than that of any other existing observatory, that for all micrometric observation better methods of eliminating personal and instrumental errors than we now possess will require to be invented.

If, therefore, a number of observers in different quarters of the country would consent to work on the same lines, the chances are that their records would be found to supplement one another, gaps to some extent disappearing, while the comparison of observations thus rendered possible might afford important independent evidence in cases of unexpected or improbable results, and help towards the elimination of the personal factor. Such a course as this is obviously only practicable where the total number of observers is very considerable, as in England. The spread of practical interest in astronomy is so rapid, and good telescopes are yearly becoming so much more accessible to the ordinary purse, that we may perhaps not unreasonably look for some consummation of the kind in the near future. Of course it is only certain branches of work that can be expected to benefit by such treatment.

Organization with another end in view, and in some respects a more feasible one than the duplication of imperfect records, has frequently been attempted. The plan is to divide and allot the wider fields of research among a band of workers, thus bringing within the range of practicability the detailed and systematic study of the whole. This has been done to facilitate the search for comets and the study of variable stars, and the method might with great advantage be adopted in other extensive researches, such as the spectroscopic examination of the sun. But although several efforts have been made to effect some systematisation of amateur work, they have too often fallen through for want of sufficiently cordial support. What is absolutely necessary to successful organization, and what, as it happens, is sadly lacking in the meantime, is enthusiasm. Organization implies, to a considerable extent at least, the effacement of the individual, the sacrifice of the

observer's liberty of action, the compression of his energies into a narrow and cramping channel, the reduction, in short, of his work (undertaken not unlikely with a view to intellectual expansion) to the driest and most machine-like drudgery. Nothing but enthusiasm can carry him through such a disgusting ordeal, a fact of which most amateurs are quite aware; and it is the consciousness, no doubt, of deficiency in the needful motive power that makes them halt on the threshold of all schemes of organization proffered for their personal adhesion.

To undertake the organization of research is the proper work of a Society. Individuals, no matter how eminent in their particular departments, lack the prestige of a corporate society, and fail to inspire the same confidence. The Liverpool Astronomical Society has assumed the function, and, though young, and hampered by its constitution as a local body, the success that has attended its efforts is most encouraging. Practical sections devoted to all the more important departments of astronomical work are now in full operation, and give promise of great results.

J. A. W. O.

MEMORANDA.

South of Equator meridian altitude .	= Co. lat. − Dec.
North ,, ,, to Zenith ,, ,, . .	= Co. lat. + Dec.
North of Zenith to Pole ,, ,, . .	= Lat. + P.D.
From Pole to horizon ,, ,, . .	= Dec. − Co. lat.

Refraction in Declination.

South of Equator is	additive.
North ,, ,, to Zenith is . .	subtractive.
North of Zenith to Pole is . . .	additive.
From Pole to horizon is . . .	subtractive.

Precession.

Precession forwards in Dec. south of equator has the same sign as for P.D., but opposite for precession backwards.

Precession forwards in Dec. north of equator has the opposite sign as for P.D., but same for precession backwards.

L. S.

CHAPTER II.

THE TELESCOPE.

[If the amateur is already possessed of as good a telescope as he can afford, his wisest course, on deciding to take up original work, is to make a careful determination of its powers,[1] and then select whatever branch of work the capabilities of the instrument point to, always provided, of course, that the work so indicated is adapted to the observer's opportunities and agreeable to his tastes. The instrumental qualifications required for the various departments of research are dealt with in the chapters specially devoted to them. It only remains, therefore, in the present chapter to offer such hints on the 'points' of a working telescope as may assist the amateur, who intends to provide himself with a new tool, to make a wise selection, and at the same time enable him to test for himself its mechanical merits. A few remarks on the care of the instrument, and on observing-houses suitable for amateurs, are added.]

A good astronomical telescope, even of small size, is an expensive luxury; and its purchase should not be entered upon without due consideration of the suitability or adap-

[1] For some general hints on telescope testing, see *Cel. Obj.*, pp. 2–4. A valuable list of test-objects, classified as dividing tests, defining tests, and space-penetrating tests, is given in Clark and Sadler's *Star-Guide*, London, 1886.

tability of the various forms and constructions to the conditions and surroundings of the intending user.

It is curious to note how differently different people go about starting an astronomical observatory. Some take upon themselves to decide on all points without any previous personal experience whatever, or without consulting any friendly expert; the result being that the instrument, having done its duty as an instructor (i.e. an instructor of the shortcomings of astronomical instruments), finds its way into the market as a second-hand instrument in a year or so. Some, again, solicit the advice of their astronomical friends all round, but as each of those friends has probably some particular line of work or some particular study most prominently before him (to which he thinks all others should be made subservient), the advice he receives is generally rather perplexing, and if attempted to be followed in its entirety likely to lead to the production of a kind of second-rate Admirable Crichton of an instrument, suitable to a certain degree for all classes of work but first-rate *for none*. Others, again, take perhaps the advice of one experienced friend, and this is much better; for if that friend be a man who has done good work, it is likely that he will become possessed of an instrument suitable at least for that one particular line. The worst of all cases, and the most unsatisfactory for the instrument maker, is that of the would-be astronomer who comes and says, 'Now I want a telescope, and I want to do some astronomical work. I don't know what that work is to be, and even if I did I don't know what form of instrument would be best suited for it; but please do the best you can for me for so much.' The instrument maker is probably unacquainted with the purchaser's position, surroundings, taste, qualifications, &c.; in fact, every factor which should

be taken into account in deciding such a question; ten to one, he, with the best intentions, advises some unfortunate course which the amateur gets thoroughly sick of very shortly, and the result is dissatisfaction on all sides.

If the amateur would take the trouble to consult a few good reliable works on the subject, so as to be able to take an intelligent view of the subject, he will find that after a little he will be able to communicate to the instrument maker his special desires, and discuss with him the applicability of the various forms to his special purpose. It is with a view to aid amateurs in this matter that the present remarks are offered.

THE MOUNTING.—In the present day it may be assumed that anyone who possesses an astronomical telescope, except of the smallest size, will not think of mounting it on any other form than the equatorial. It is the only form in which the heavenly bodies can be followed by a uniform motion of the instrument round one axis. If the axes be placed in any other position, it is not possible to follow the object without a double motion, and that varying in a most complicated manner; nor is it possible to apply clockwork, except with the most complicated contrivances. The superiority of the equatorials for astronomical purposes have always been recognised since their first introduction, but up to late years it was not possible to procure these, except of great complexity and corresponding expense. Now, however, when really practical little tools suitable for mounting small instruments can be obtained at prices quite as low as the simplest alt-azimuth, that difficulty is removed, and no one probably will think in the future of using anything but an equatorial for astronomical purposes. [There are cases, however, in which the alt-azimuth (provided with circles) has its advantages. One of the most suc-

cessful discoverers of comets at the present time uses such a mounting, as more suited to that particular class of work.] Of the various forms of equatorials, also, it will hardly be necessary to treat in this chapter, as it is only intended that the remarks here made should have reference to refractors up to about 8″ in diameter, and reflectors to 12 or 25, and there is for these sizes really but one type of equatorial usually used by the instrument makers of this country—i.e. the so-called (but misnamed) German form. The other two distinctive types—the old English divided Polar axis (such as the Greenwich refractor) and the biforked Polar axis (in which the telescope is swung between a pair of jaws forming a prolongation of Polar axis above upper bearing)—need not be discussed, as they are not practically procurable.

The first and most important point to look to is the stability of the instrument. This depends on various conditions. Suppose the foundation, or pillars, or whatever the instrument be mounted on, to be sufficiently firm, the stability depends on the proper proportioning and construction of the axes and their bearings, and the general strength of the body or framework. It may be asked what size and length should the axes be in proportion to the diameter of objective or special size or form of telescope, &c. This is a question it would be almost impossible to answer, as so much depends on the construction and arrangement of the parts.

A rough, but fair test of the stability, however, may be made thus: Turn the telescope to a star (a Polar star preferable if there be no clockwork), and put a high power on telescope, say 200 for a 3-inch objective, and try if you can focus satisfactorily and comfortably without causing the image to dance about in the field. If the image is not

steady in field, it will be impossible to focus satisfactorily, and the stand is defective.

It may now be asked, How am I to specify to an instrument maker the degree of stability necessary, or how am I to know beforehand that the instrument he recommends me will have the requisite stability? To this the best answer is: Go to an instrument maker of repute, and tell him you want an instrument of such a size for star-gazing, or for micrometrical work, or spectroscopic work, as the case may be, and you may be perfectly sure he will not risk his reputation by recommending you anything unsuitable.

Quite apart from stability, there is a certain quality of 'rigidity' which is very desirable. This is generally not so much a matter of mere strength of axes, &c., as of proper construction and arrangement of the clamps and slow motions. Every mounting to carry a 4″ or over refractor ought to be provided with clamps and slow motions in right ascension and declination, and if these be not properly constructed there is a want of rigidity and definiteness of position of instrument.

To test this, point instrument as before on a star, clamp both right ascension and declination; now press finger with a few pounds pressure against side of rack tube, trying it up, down, right and left. On application of each successive pressure the star will be seen to move slightly in field (for no instrument is absolutely rigid), but on releasing the pressure the image ought to return to almost exactly the same place as before.

The clamping handle should clamp very decidedly and promptly; a quarter turn of handle should suffice to clamp or unclamp, and, when clamped, the telescope should be quite firm and not movable except by considerable force.

The slow motions should work with as little 'back-

lash' or 'loss of time' as possible—i.e. after working in one direction, if the handle be reversed the motion of the instrument should respond almost at once to the reversed motion of the handle.

There are several forms of slow motion used. For declination movement, generally a screw working into a sector, or (what is called the German form) a screw bearing directly upon a clamp which is kept in good contact with it by a spring, is suitable for small, light instruments. For right ascension movement, the slow motions are generally either of the form of a tangent screw of some kind or a differential gearing in clock shaft which, when worked in one direction or other, causes a temporary acceleration or retardation of rate at which clock drives endless screw. Whatever be the form used, if the instrument stands the test given above it is sufficiently good; but if a differential gearing be used, see that it is of a form in which the additional wheels only come into use when the slow motion handle is turned. Some forms of differential slow motion introduce several wheels directly into the clock train; there is no necessity for this, and every wheel added between governors and clock train is a disadvantage.

Another point to be considered about equatorial mounting is its general convenience. Some mountings have inconveniences attending them which are never discovered till they come to be used; but here again it is necessary to trust, to a great extent, to the instrument maker. Any instrument maker of experience has of course had all matters of convenience and inconvenience brought prominently and constantly before him; his business is to grapple with these matters, and they may generally be safely left to him. A few points may, however, be mentioned.

See that the telescope has, to as large extent as possible,

circumpolar motion—i.e. that up to as high an altitude as possible the telescope can be allowed to follow a star without requiring reversal when star passes meridian. In some instruments, the clock and other parts of apparatus are so placed that when the telescope has followed the star from E. to meridian, or just a little beyond, it (the telescope) comes against some part of the stand or clock, and the whole instrument has to be reversed to other side of pier, and the observation re-commenced. This is often very vexatious, as it is just the best possible position for observing. There is no difficulty in so arranging matters that any star up to 75° or 80° altitude can be observed without necessary reversal of instrument. Another convenience resulting from this is, that there is thus generally a possibility of a choice of two positions in observing any star up to that altitude—i.e. with telescope E. or W. of Polar axis, if star be near meridian; or above or below Polar axis, if star be to E. or W. See also that if motion of telescope is liable to be stopped near meridian by some portions of instrument, that it be not likely to be so stopped by any delicate part, such as clockwork, &c. This is another great convenience.

All clamping handles and slow motion arrangements should be convenient to hand of observer while he is in a position for observing.

Circles should be clearly but not too finely divided. In the smaller instruments, in which accurate determinations of position are rarely wanted, it is a mistake to employ circles too finely divided. It is rarely that the vernier in right ascension circle is ever used; generally the zero point is quite sufficient. Amateurs have not often the means of knowing the time so accurately, or the facility of calculating the refraction so conveniently, that they require to set

the right ascension circle nearer than to fifteen seconds of time.

For very small telescopes of simple but efficient construction, some makers use circles printed on paper, which are clear and easily read, and quite as accurate as the ordinary class of metallic circles on the less expensive stands, and can be replaced when required at a cost of a few pence.

On the better class of instruments various convenient appliances are added by different makers for different purposes.

Readers, by which the circles can be read from eye-end of telescope, &c., these are just so many labour-saving contrivances, very useful and very convenient, but without which it is quite possible to do the very best work.

In equatorial instruments, as well as in most mechanical instruments, there are two totally different classes of 'cheap' instruments.

There is the instrument which is cheap because it is inferior in every way, badly designed and constructed and clumsily made. This is dear at any price. But there are also instruments sold at low prices by good makers which are cheap; not because they are inferior in any way, but because they have been simplified down, and all unnecessary work and finish dispensed with. They do not profess to do as much as the other class of instruments; but what they do they do well, and they can have such additions made to them from time to time as the purchaser may desire.

Except in very small instruments, it is much better that the endless screw driven by clockwork gears into teeth cut on a long radius of sector than into teeth on an entire circle, which must necessarily have a short radius. For

any given error in screw or bearings, the effect or motion of instrument will be in the inverse ratio of radius of toothed circle.

For large equatorials, those 5″ or over, it is better that the clock-screw have a square and not a V thread.

CLOCKWORK.—A great variety of these are used by different makers, all more or less effective. Except for extraordinary purposes, the ordinary frictional governor is probably the best, as it is certainly the most common, form.

The principal points to be looked to in the clock are:

1st. Sufficiency of power—i.e. not only sufficiency of power to drive instruments under ordinary circumstances, but sufficient also to leave a large margin for possible and probable hitches or differences in force required owing to want of balance or any of those numerous causes which tend to vary the friction of any instrument.

To give an idea of what may be called sufficient, measure the height the clock-weight falls in an hour, and multiply this in feet by the number of pounds weight; the product will be the number of foot-pounds of energy available in each hour.

A 4″ telescope should not have less than 75, and a 6″ less than 200, foot-pounds of energy per hour.

These rough figures will give an idea of what is required, but of course much depends on the character of instrument, and its weight, and the fineness of finish of bearings, &c.

2nd. The train between clock-governor and clock-screw should be as simple as possible, with as few wheels as possible, as short shafts as possible; and, lastly, the gearing up between clock and screw should be as far as possible made with spur instead of bevel gearings. It is

not the slightest consequence how complicated the train be anywhere else except between governor and screw, but every avoidable wheel introduced there increases the chance of error.

3rd. The governor or regulator should be heavy, and have as much momentum as possible, to enable clock to get over small obstacles without perceptible jerk.

Various forms of improved governors have been introduced from time to time, but none are better than the simple frictional governor for short periods, and this is what is generally required.

If the telescope be required for photographic use, in which case the star must be kept constant in position for two hours without $\frac{1}{10}$ of a second displacement, the only resource is that of a uniform clock controlled electrically from a pendulum clock; but this arrangement is too complicated to attempt to describe without diagrams. It should be remembered that all these points are more or less important according to the delicacy of the work proposed to be undertaken. If the instrument be intended only for gazing at planets, stars, and comets, these points are of comparatively little consequence; but an instrument quite equal to this work would be useless if it were required to use very high powers for dividing difficult double stars, &c.; and again, an instrument might be sufficiently stable and rigid for this last purpose and not be sufficiently so if delicate micrometrical work were to be attempted.[1]

[1] Much stress has been laid on the driving clock as an indispensable adjunct to the equatorial, though, from the amateur's point of view, it is still an expensive luxury; and, if the telescope is not to be especially devoted to micrometrical or photographic work, the ordinary tangent-screw, worked by hand, will suffice for most purposes. A sidereal timekeeper is almost a *sine quâ non* in the effective use of the equatorial mounting; but an old-fashioned eight-day clock,

THE TELESCOPE.—Concerning the great question of refractor *versus* reflector there is much diversity of opinion. It would take more than one entire chapter to go fully into the arguments on both sides, but shortly stated the facts stand as follows.

[These remarks only apply to the smaller sizes of instruments. For the larger sizes, the conditions are modified.]

If it be desired to obtain for a given sum the greatest possible amount of light-grasping power, a reflector will probably be preferred. This is more especially the case when the purchaser is of a mechanical turn of mind, and for so long as the silvering of the mirror is looked forward to as rather a piece of amusement or pleasure.

It is a noticeable fact, however, that the preference for reflecting instruments is dying out in this country, and many are replacing their reflectors by refractors; after a while, the resilvering operation becomes tiresome, the instrument gets neglected, and the owner begins to sigh for a refractor which he can leave for twelve months and come back to find in perfect order and ready for instant use. At the same time, as mentioned above, the reflector is capable of doing the very best work, and no doubt a greater amount of light-grasping and separating power can be obtained with them than with the refractor for the same money. The position, too, of the observer, in case of a Newtonian, is more comfortable than in case of a refractor.

It is not, however, so well suited for micrometric work, on account of the unstable character of the various adjustments.

The great advantage of a refractor to an amateur (who

beating seconds, with a slight alteration in its wheel work and dial, makes a capital substitute at a merely nominal cost.—W. S. F.

can only use it during intervals snatched from his other work) is the permanence of its adjustment, its freedom from likelihood of injury, and the certainty of its being always ready for him when he is ready for it.

As regards the relative defining powers of the two instruments, much has been written without any definite result, the fact being, that either instrument, if good, is capable of the best work. Some first-rate observers with refractors have utterly condemned reflectors, while some who have done good work with reflectors condemn refractors. This only shows that astronomers have their idiosyncrasies as well as others, when undoubtedly good work has been done with both.

An observer who has worked for many years exclusively with reflectors is actually shocked at the amount of outstanding colour surrounding stars as seen in refractors, and wonders how anyone can work with them. On the other hand, the worker with refractors actually does not see the colour, he is so accustomed to it, and nothing annoys a veteran observer more than the inevitable exclamation of the tyro on first looking at a bright star, 'Oh, what beautiful colours!' Again, to those accustomed to work refractors, there is something unsatisfactory in the appearance of a star in a reflector.

'They showed me something which they said was Saturn, and I believed them,' was the description a celebrated foreign astronomer gave of his view of Saturn through Lord Rosse's celebrated reflector, and yet everyone knows that this instrument did do excellent work in the hands of its constructor.[1]

[1] In the choice between refractor or reflector two important points have to be considered; one is the space available for the telescope to work in, and the other is the amount of money to be expended

As to tests for, and testing of, objectives and mirrors, it is almost impossible to give any directions which will

on it. Where a large aperture is required, it must not be forgotten that a refractor, from its relatively greater focal length, will need a much larger observatory than a reflector of equal light-grasping power. In perhaps the majority of cases, the amateur is circumscribed both in pocket and sky room; and when this is so, there can be scarcely any doubt that he will get more optical power, in less space, with equal outlay, from a reflector than a refractor. Should, however, the expense be a secondary consideration, with unlimited room wherein to build the observatory, then a large refractor might be preferable. In saying this, no disparagement is intended towards large reflectors, which are quite capable of doing any work that the other form of instrument can accomplish; but their open tubes are more susceptible to atmospheric disturbances, and radiated heat from the observer's body; and, moreover, their silvered specula cannot be considered so permanent as object-glasses. With proper care, the silver film will last a long time, but, nevertheless, it *will* need renewal sooner or later; and if the observer has not the inclination to undertake it himself, he must send it away, at the risk of accident in transit, and perhaps at a time when it can be ill spared from its work. On the other hand, much has been made of the difficulty of using a micrometer with a reflecting telescope, on account of varying adjustments, &c. This is, however, more imaginary than real; inasmuch as the adjustments can be made almost as permanent as those of a refractor, and, if a revolving body be dispensed with, the position angles can be made to agree precisely with the ordinary achromatic. Nor does the illuminating apparatus present any more difficulty in the one case than the other. Whichever kind of telescope is selected, the eye-pieces belonging to it ought to *slide*, and not to *screw*, in the adapting tube, as they are then changed with far less labour and loss of time, and they are not so likely to be dropped when the fingers are benumbed with cold. By means of collars suitably placed they may be arranged so as to be in focus when pushed home, and, therefore, when one eye-piece is focussed the whole range of powers may be used without touching the focussing screw. Whatever may be said to the contrary, it is desirable to avoid excessive wear and tear of the rackwork; as observers who have worn out rack and pinion by years of hard usage well know.—W. S. F.

enable a tyro to detect whether his telescope is good or not. It would be about as hopeless a task as to try to convey to a person wholly uneducated in art, and who had never seen anything but daubs, how to know a well-painted picture. One great mistake which beginners fall into, and which it is to be feared most text-books rather encourage, is that of supposing that, because a telescope of a certain size should divide such a star, the telescope is necessarily bad because when he puts his eye to it he does not see it so divided. 'The most important part of the telescope is the man at the small end,' said a celebrated astronomer. There is such a thing as education of the eye, and even though a person have good sharp ordinary sight, it by no means follows that he will see nearly as much with a telescope at first as a person of very ordinary sight who has educated his eye by experience.

Text-books on the subject, by giving lists of objects which are capable of being divided by different sized telescopes, and pictures (?) of planets, &c., as they should be seen, rather encourage the fatal mistake.

An enthusiastic amateur receives a telescope he has been waiting for for months; meanwhile he has studied up the text-book on the subject, and he finds that a telescope of the size of his should have a power of x and divide such and such stars. The moment he gets his instrument into position he puts on his highest eye-piece, and points to these objects, and great is his disgust to see something like a ball of cotton-wool on a flaming gas-lamp. He is not told that this object can be so seen only under favourable circumstances and with *educated eyes*, or that the beautiful pictures he sees of Saturn or Jupiter are either the result of a number of observations, or what was seen on some exceptional occasion, and he condemns at

once what, in experienced hands, may prove an excellent instrument.

An experienced observer judges of a telescope not so much by trying what stars it will divide as by the appearance of any particular star which he is familiar with. A few hints, however, may be of use. The three principal faults to look for are: over or under-correction for achromatism; under or over-correction in spherical aberration, and want of centering of one lens or another.

1st. *Chromatic Aberration.*—If properly corrected, the outstanding light, when telescope is focussed on a star, has been variously described as violet-blue, or claret colour. If it is decidedly greenish-blue, the objective is over-corrected; if red, the objective is under-corrected.

Several stars should be observed before an opinion is formed, because with a very red star there is always apparently too much red on fringe; or, with a very blue or green star, too much blue.

2nd. *Spherical Aberration.*—Turn the focussing handle backwards and forwards, so as to bring eye-piece inside and outside focus a sufficient quantity to enlarge the image to a very sensible disc, and observe the relative appearance of these discs (which are sections of cone of rays) inside and outside focus. With exception of the distribution of colour, these two should appear as much alike as possible. If the light be more concentrated towards edge of disc inside focus, and centre outside, the objective is under-correeted. If the light be more concentrated towards edge of disc outside of focus, and centre inside, it is over-corrected. Observe, also, if there be a general uniformity of distribution on disc, or if it be inclined to form one or more rings of light.

Owing to diffraction, the disc will always appear to be

formed of a number of rings, but these should be as uniform as possible.

3rd. *Centering of Lenses one on another.*—Bring a bright star into centre of fixed focus, and observe if the distribution of colour *all round* is uniform. If there be more red on one side and blue on other there is a fault of centering somewhere; now turn round eye-piece half a turn. If colours remain as before, the fault is in objective; if colours are reversed, fault is in eye-piece.

Observe also if the disc of light inside and outside focus be quite round and symmetrical, and that there be no distinct rays or jets of light in any definite position emanating from the image when it is in focus.

Of course, before these observations are made, the objective must be put into perfect adjustment.

To observe if glass of which your objective be made be homogeneous or not: turn instrument on a bright star, take out eye-piece, and place eye so that full blaze of light enter the pupil of eye. The whole objective should now appear full of light; observe if this is quite even, or if there be objects like feathers or threads across it; any conspicuous vein or want of homogeneity will be readily detected this way.

Focussing.—This is an operation rarely properly performed. The general plan with tyros is to turn the pinion-head slowly till image seems sharp; the result being that it is hardly ever turned enough, and the eye is strained. The plan pursued by all experienced observers is to turn the button quickly backwards and forwards (don't be afraid of injury to rack; there is more damage done to rack by non-use than over-use). Bring the eye-piece decidedly outside and inside the focus each time; after a few turns backwards and forwards, you find that a certain 'excursion' of pinion brings

you equally on each side of focus; make the object equally indistinct and then give a half excursion, which is the true focus. This after a little practice can be done with great accuracy.

Another mistake made by beginners is that of crowding on too much magnifying power. In inquiring about the quality of some particular instrument a tyro almost invariably asks, What is the highest power you can use? an experienced observer will ask, What is the lowest power with which you can do so and so? Always use the lowest possible power that will suffice to show any object; and if any sensible atmospheric disturbance is visible, with this you may be assured—there is no use in looking at objects which would require a higher power.

Care of Instrument.—So far as the mechanical part is concerned, there need be nothing special mentioned; *keep everything clean*, do not let dust settle on delicate parts, and when shafts get stiff and appear to want oil wipe off the old thick oil before you put on fresh. There is more harm done by over-oiling than not oiling at all.

Respecting the wiping of object-glass, great care should be taken to avoid risk of injury. Much has been said and written of the relative advantages of wash-leather, cotton, linen, and silk cloth. The fact is this, any of these can be used with perfect safety if properly done. The great danger is the dust which lies on surface of objective. This is often very gritty, and if you take any of these cloths and begin to wipe hard (without having previously removed the coating of dust), you will almost assuredly scratch your glass.

First, carefully remove the dust by a camel-hair brush or by 'flicking' it with a soft cloth; or, if there be a caked layer on surface, breathe on it and wipe very gently with a small piece of soft cloth, which you then throw away. When

this is removed you may fearlessly wipe and polish the glass, provided your cloths have been carefully washed to remove adventitious matter and have been kept from dust after.[1]

It is a fortunate circumstance that the outer surface of an objective, which is most likely to require cleaning often, is of *hard crown* glass. To clean the surface of back lens, which is of soft flint, requires still greater precaution and care.

[1] In cleaning an object-glass or eyepiece lens, after the loose particles of dust have been removed by a camel-hair brush, there is no better medium than soft tissue-paper, aided by the breath; it is superior to either chamois leather or old silk, and it effectually removes the atmospheric film, with its suspicion of greasiness, that inevitably collects on such surfaces, no matter how jealously guarded. Silvered specula ought not to be too frequently 'touched up' with the polishing pad; less harm is done by leaving them alone. When very badly 'dewed,' the quicker the moisture is got rid of the less liability is there to form stains; but it is better, where practicable, to place the mirror in a strong draught of dry air than before a fire. Of course it seems hardly necessary to add that the film must on no account be rubbed or touched when damp. Some observers fit a layer of cotton wadding inside the speculum cover to absorb the extraneous moisture; and, where the mirror is taken out of the telescope, it is not a bad plan to have a vessel containing dried calcium chloride or strong sulphuric acid placed near it for a similar purpose. If a telescope is carried indoors, after being used at night, the object-glass or speculum must invariably be covered by its cap, or it will certainly be dewed on entering the warmer atmosphere of the house. But it is much better to have an observatory, however humble, and to leave the instrument in it. For protecting bright metallic surfaces from oxidation, such as R.A. and Decl. axes, clamps, circles, &c., and also for its lubricating qualities, vaseline is strongly recommended, as not being liable to the gumminess of ordinary oils. The boxes in which eyepieces, micrometers, and other accessories are kept should be, preferably, made of metal rather than wood, as the former accommodate themselves much more rapidly to change of temperature, whilst some kinds of woods emit a resinous vapour, which is no improvement to delicate glass surfaces.—W. S. F.

PILLAR, PIER, OR OTHER SUPPORT FOR SMALL EQUATORIALS.—There is no use in having a solid well-made equatorial unless it be mounted on a firm pillar or base. For large instruments stone piers are always required. Small instruments (four inches and under) can be, and have been, used on strong tripod stands, but their full powers cannot be utilised, and a good instrument is simply wasted unless properly supported. For very small instruments which can be carried bodily by a person, a good plan is to have a fixed pillar or stone in a convenient place, and to carry out the instrument when required; bolt it down to a metal cap on stone, and have marks made so that it can be brought approximately into adjustment without loss of time. If too large for that, stand can be left out and telescope only lifted off and brought into a place of safety. In the latter case it is necessary to have a well-fitting tin cover to put over stand and protect it from weather. If larger still, it is necessary to have an observatory.

SMALL OBSERVATORIES FOR AMATEURS.—Very often a would-be observer is heard to say, 'Oh yes, I would purchase a telescope with pleasure if I had a place to put it, but I cannot go to the expense of building a special observatory for it.' For small observatories the form of roof called the Berthon is very efficient, and if the observer has a mechanical turn he can probably make it himself.[1] A still cheaper form, however, is the sliding-roof observatory.

To make one of these for, say, a four-inch telescope of five feet focus, six uprights are erected, forming a double square of about sixteen feet by eight feet. Four of these are connected together near ground by horizontals to carry flooring, and they are all connected together at top by two

[1] One such observatory, that we know of, was completely built for about 6*l*.

pieces of timber sixteen feet long, and three across of eight feet long, forming the wall-plate. One of the eight-foot squares is now strutted in on sides, and a door placed in any convenient position; this forms the observatory eight-foot square. A peaked roof is now made, framed together independently of the wall, and this is mounted on four iron grooved rollers, which can be procured at any ironmonger's, which rollers roll on the two sixteen-foot longitudinal wall-plates. It is desirable to screw bars of light iron on top of wall-plate for rollers to run on. The height of wall is made such that, when telescope is turned, horizontal roof can be rolled off.

In this form of observatory, as the roof rolls completely off, there is much less inconvenience experienced from currents of air of different temperature than in a roof with a simple slit or chase. It may be thought that there is very little protection to observer; but the writer has had experience of many forms of observatories, and he never found anything so personally comfortable and so free from draughts as this.

Such an observatory, if made by a local carpenter, need not cost more than 8*l.* or 10*l.* The roof may be covered with tarred felt or zinc.

[The efficient lighting of an observatory is a matter that demands some little thought and consideration. Where gas is procurable it will doubtless be preferred on account of cheapness and convenience, though it has many drawbacks. It is liable to be blown out by the wind; it deposits soot upon any piece of apparatus in which it may be enclosed; gives off considerable heat, whilst the results of its combustion are very deleterious to silvered surfaces; and a gas-jet is not so easily and quickly turned down as it ought to be for observatory purposes. The incandescent

electric lamps of Swan, Edison, and other makers are free from the foregoing disadvantages, and lend themselves readily to every possible use in which light is required. For the illumination of circles, micrometer or transit eye-pieces, &c., such a light is simply invaluable; and, even if the requisite current is supplied by a primary battery, the cost is comparatively trifling. These lamps are rapidly coming into use in various observatories, and will doubtless ere long entirely supersede their smoky, greasy, and unpleasantly odorous rivals.]

H. G.

CHAPTER III.

THE SUN.

NATURE AND ADVANTAGES OF SOLAR WORK.—It has always seemed strange to us that the study of the Sun should not be the branch of astronomy most popular amongst amateur observers. The Sun is of such paramount importance to us, as our fire, light, and life, and the ultimate source of almost every form of energy in action on this our earth, that no other celestial body can compare with it for a moment. And no other affords so many and such interesting problems for our solution. What is the amount of the light and heat it is pouring forth every moment? what the source of all that tremendous energy? how is it kept up? and what becomes of it? are questions of the very first interest. Then there are the problems which a study of its surface presents. What are sun-spots? how are they formed? what is the explanation of their periodicity? these are but a few of the questions which arise as we watch the Sun, and to which the Sun only can supply the answer.

And it is so beautiful an object. The silver glow of the branching faculæ, the strange shapes and wondrous changes of the spots, the loveliness of the spectral colours (if we turn the spectroscope upon it), the delicate forms and weird transformations of the prominences, what other

object can show us the like? And it is so easy to observe. No sacrifice of the night's rest demanded, no interference with the ordinary habits of humanity, no exposure to the bitter cold of a winter midnight. The Sun not only has the most to offer to its votaries, but it asks the least from them. It should surely be the one especial object of the amateur's attention.

And there is abundant room for work. We know but little of the Sun even yet. To this very day it is not universally agreed as to whether sun-spots are depressions or elevations, whether they are breaches in the photosphere or dark substances floating above it. With such a very elementary question not yet perfectly settled we certainly cannot regard the field of solar research as already reaped.

There are two principal departments of solar work: the examination of the Sun's surface and the examination of the Sun's limb. The latter department is the province of the spectroscope alone; the former offers a wider field, and may be dealt with either by means of the telescope or by the spectroscope, or the record of photography may be substituted for direct eye observation. In the present chapter we shall confine ourselves to the telescopic examinations of the Sun's surface. The chief features of the surface which call for attention are the spots.

Spot Observations.—Something may be done simply by the persistent and attentive watching of the surface. The remarkable observations which the Rev. Father Perry has recently published of faint 'temporary' spots almost evanescent in character might have been revealed by such a watch. So, too, changes in the forms of the ordinary spots are sure to be seen sooner or later by the constant observer, even if he never be so fortunate as to witness so grand an out-

burst as Carrington and Hodgson saw on September 1, 1859. Then there is the question already alluded to as to whether sun-spots are depressions or not. It is most generally believed that they are, or at least that the dark umbra is at a lower level than the fainter penumbra surrounding it, since the penumbra is usually the wider on the side of the spot further from the centre of the Sun, and when near the limb the umbra is hidden as if by the higher surface of the photosphere. But this is not always the case, and the exceptions are so numerous as to call for a systematic examination. The fact that spots when seen on the limb so frequently appear as notches does not decide the question so completely as might at first be thought, for if they are clouds, not hollows, they would hide a part of the limb, and equally cause the appearance of a notch.

M. Faye believes that sun-spots are cyclonic in character, and regards this as the key to their formation and nature; but we need further evidence than we at present possess before this theory can be unreservedly accepted. Indications of cyclonic motion should, therefore, be carefully looked for; these will be found in the direction of the penumbral rills, or in the markings round the edge of the nucleus, rather than in any rotary motion of the spot as a whole.

Uncorroborated Observations.—There are several important observations by skilled observers which at present are without sufficient corroboration; the observations themselves being such as we should not readily accept, and yet the observers being of such eminence and reputation as to almost compel acceptance. Such is the celebrated observation of Dr. Peters, in which he saw flashes of light pass and repass across the umbra of a spot with the speed of electricity, or the recent one of Trouvelot, when he observed

a shadow cast by a facula on the penumbra of a spot. Such, too, are Father Perry's observations of rapidly moving spots. The observer should always be on the *qui vive* to detect such extraordinary phenomena, but when seen it is his first duty to take for granted that he may be merely the victim of appearances, and to test the reality of what he thinks he sees in every possible way. Contrast and atmospheric disturbances have much to answer for in solar work, which is particularly liable to such influences, dealing as it does with the brightest body we know, and one which must always be observed through more or less heated, and therefore tremulous, air.

There is no need to tire of delineating the general forms and minuter details of sun-spots; the more we can learn of their structure the better. There is an important point, for instance, in which the writer finds his own experience in contradiction to that of many of our best observers. It is commonly stated in text-books that the penumbra of a spot is least dark where it borders on the umbra, and illustrations are often given showing that part of the penumbra as positively bright. He believes that, so far from this being the rule, it is quite exceptional, and that *usually* (not invariably) the penumbra darkens towards the umbra, and that the phenomenon as ordinarily described is merely an effect of contrast. As this is a feature on which much stress has been laid in framing sun-spot theories, it would be well worth while to examine the point further. There are observers, too, who regard some of the groups of small spots often seen as really consisting of but a single large spot largely hidden by faculous or photospheric matter irregularly distributed above it and permitting small isolated portions of it to be seen. Such groups should, therefore, be specially studied.

METHOD OF MAKING EYE OBSERVATIONS.—The best method of making eye observations is by projecting the Sun's image upon a suitable screen, firmly fixed at a convenient distance behind the eyepiece of the telescope. The eyepiece, which should be only of low power, will have to be drawn out a little way, and a very small motion will bring the image of the Sun which is projected on the screen into the most exact focus. Ten or twelve inches will be found to be a very convenient size for the diameter

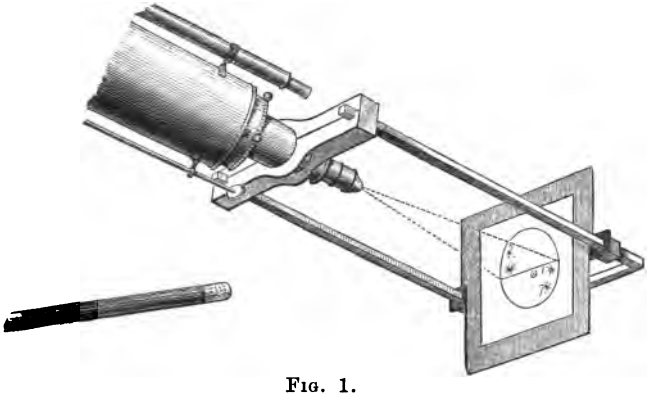


FIG. 1.

of the Sun's image. The use of the method of projection so entirely gets rid of the serious difficulties occasioned by the great light and heat of the Sun, and affords such an easy means of accurately delineating the spots both as to size and position, that it should be always adopted, though it may be well to supplement it by direct observation through the telescope.

SKETCHING SOLAR SPOTS.—In the accompanying figure (fig. 1) is shown the sketching-board attached to the telescope for solar work at Stonyhurst Observatory, where the

delineation of sun-spots has received special attention with highly successful results. The whole apparatus is light, but rigid, and when a black cloth is thrown over the observer, or a large screen fastened near the object-glass of the telescope, every detail of the solar surface can be watched with the greatest ease. A circle $10\frac{1}{2}$ inches in diameter (the size preferred by Father Perry for daily work) is drawn on the paper with a single ruled diameter, and when this is fastened on the board the Sun is focussed on the paper so as exactly to fill the circle, whilst a spot runs parallel to the ruled diameter. An outline of the umbra and penumbra of each spot, and also of the faculæ, is made as quickly as possible, and then the details are filled in. If the definition is good, the observer may sit quietly watching the whole disc and noting the changes that take place in the faint spots. These faint spots appear in every heliocentric latitude, and alter so quickly that only a few of the remarkable ones admit of being sketched.

THE MEASUREMENT OF SPOTS.—By sufficiently careful amateurs good work may be done in measuring the areas of the spots and faculæ. The method adopted at Stonyhurst is thus described by Father Perry:—

'I use an etched glass consisting of concentric circles, &c., radii 5° apart. The circles were calculated by the following simple method.

$$\text{Diameter of picture } 10\tfrac{1}{2} \text{ inch} = 2\,r$$
$$r_1 = r \sin 10^\circ = 23^{\text{mm}}.156\,;\ r_2 = \ldots$$

Areas of projections =

$$\pi\,(r_1^2 + \overline{r_2^2 - r_1^2} + \ldots) = 1684{\cdot}46 + \ldots = m_1 + \ldots$$

Areas projected = a central circle + concentric rings (approx.).

Area of ring =

$$2\pi \frac{R_1 + R_2}{2} \cdot \frac{\pi R}{18} \because 10^\circ = \frac{2\pi R}{4 \times 9}.$$

$\therefore$ Areas projected =

$$\pi . \overline{\frac{\pi R}{18}}\Big|^2 + \frac{\pi^2 R^2}{18} \overline{(\sin 10^\circ + \sin 20^\circ + \sin \overline{20^\circ + \sin} 30^\circ + \ldots)}$$

$$= 2\pi R^2 (0{\cdot}005231 + \ldots.) = 2\pi R^2 (s_1 + \ldots)$$

Let n = area of spot on pictures
,, x = ,, ,, ,, ,, sun $\Big\} \therefore x = n.\frac{s}{m}$ in terms of hemisphere.

'I used a millimètre scale in preference to fractions of an inch, as I possess an excellent millimètre scale. I have formed tables of $\frac{s}{m}$ to simplify the work, and the areas are measured on the pictures by aid of a second etched glass ruled in square millimètres. By aid of the two glass scales and the numerical tables the areas are at once obtained with, I think, great accuracy.'

Determination of the Position of Spots.—It is by all means to be recommended that the positions of the spots under examination should be carefully observed, and the corresponding heliographic latitudes and longitudes deduced. The value of any series of solar observations will be greatly increased by such determinations, and their interest not less so. For it is by no means always easy to identify by eye observation alone a group from day to day, as it is carried across the visible disc by the Sun's rotation on its axis; and the need of some means for securing such an identification is sure to be felt when cloudy weather prevents the Sun being seen for two or three days. Even if the groups were far more stable than they are, a break of three or four days in the observations would often

render it difficult to recognise them. But as it is, not only will perhaps half the groups on the Sun have greatly altered in shape and size, but their apparent relationship to each other will have been altered by the effect of foreshortening, new spots will have appeared, old spots have vanished, and the entire aspect of the Sun have altered. But if this is the case after a few days' interval, much more difficult is it to recognise a spot on its second appearance at the east limb after having been lost to sight for a fortnight.

The easiest mode of determining the heliographic latitudes and longitudes of the spots is by preparing a series of discs of the same size as the image of the Sun on the screen, each disc showing an orthographic projection of the Sun for some selected date. The simplest way would be to prepare eight discs corresponding to the dates when the heliographic latitudes of the Earth as seen from the Sun, or, in other words, the centre of the Sun's disc as seen from the Earth, are respectively 0°, 1°, 2°, &c., to 7°; the highest heliographic latitude of the Earth being about $7\frac{1}{4}°$. As the poles of the Sun are always practically on the limb, the lines of longitude will be the same on all the discs of the series, but the apparent curvature of the lines of latitude will vary considerably from time to time. The most important variation to be kept in mind is that of the position angle which the Sun's axis makes with the circle of declination, the N. end of the Sun's axis at one time being $26\frac{1}{2}°$ W. of the N. point of the disc, at another time as much E. The disc, therefore, ought to have its circumference divided into degrees, so that when the true E. and W. points have been ascertained by allowing the diurnal motion of the Earth to carry the Sun across the screen, and therefore the N. and S. points can

be inferred, the disc can be adjusted to its proper position by turning it until its axis is inclined at the proper angle to the true N. and S. line. The positions of the spots can then be read off with the greatest ease, and with accuracy to the nearest whole degree. The longitude read off will, however, only be the longitude on the visible disc of the Sun; it will not be longitude from any adopted prime meridian. The prime meridian used by Carrington, and at Kew and Greenwich, is the one that passed through the ascending node at mean noon, Jan. 1, 1854. The three required items, i.e. the position angle of the Sun's axis and the heliographic latitude and longitude of the centre of the disc, are given in the 'Companion to the Observatory' for every five days. Calling the longitude of the central meridian zero, and longitudes west of the centre positive, whilst those to the east are negative, the longitudes thus diminishing from west to east, the true heliographic longitude of a spot may be deduced from the observed longitude as seen on the disc by adding it algebraically to the longitude of the centre of the disc.

But if greater accuracy is required, Carrington's elegant and effective method should be followed. A pair of cross wires are inserted in the primary focus of the telescope, or two cross lines are drawn on the screen. These wires or lines must be inclined at an angle of 45° to the circle of declination. The telescope is then firmly clamped and the diurnal motion is allowed to carry the Sun across the screen, and the times of the contacts of the limbs of the Sun and of the various spots with the cross wires are carefully noted. A sample observation with its reduction is given at the end of this chapter (p. 53). Greater accuracy still may be attained by the more troublesome and much more expensive method of taking a photograph of

the Sun, and measuring it by means of a suitably constructed micrometer.

THE PROPER MOTION OF SPOTS.—With the power of determining the latitude and longitude of the spots, and therefore of identifying them from day to day, the interest of watching the Sun is greatly enhanced. One day a small district will appear perturbed; there are a few faint markings that can be hardly termed spots. The next day two or three small spots are seen further on the disc, and we learn on computing their heliographic latitude and longitude that they lie within the district that appeared disturbed on the previous day. The next day, a long irregular stream composed of many spots is seen yet further on the disc, and we learn in like manner that it is really the same group as was seen on the previous day, though its appearance has entirely altered. Of this stream the first spot is the largest, darkest, and most regular in shape, and on the following days it will rush forward with great rapidity, presenting the spectacle of an object many thousand square miles in area, travelling at a speed of 7,000 or 8,000 miles a day, whilst its neighbours remain all but stationary; stationary, that is to say, with respect to the general surface of the Sun, for of course the Sun's axial rotation is all the while carrying them, and all the other spots, faculæ, &c., rapidly forward. To add to the mystery, it is the moving spot which preserves its shape, symmetry, and size; indeed, it generally grows pretty rapidly, whilst the stationary spots in the middle of the group become smaller and fainter, and before long disappear. The last spot or spots, however, increase, but less rapidly than the first, and show little or no evidence of proper motion. The first spot soon pauses in its forward motion, yet the sudden halt does not seem to disturb its condition; on the other hand, it very fre-

quently happens that the following spots which have shown no such irregularities in motion all die away, and leave only the first spot, now round, regular, well-defined, and perfectly stationary. This is, in brief, the history of a large and important class of spots, the facts concerning which could only be wholly brought out by means of proper determinations of position. It sometimes happens that the future leader of such a group is in the early days of the group not the first spot, but near its centre, it may be, a small spot perhaps, and in no way distinguished in appearance from its comrades, the first indication of its future supremacy in such a case being frequently given by its developing a much higher rate of motion. It will thus attain the position of leader first; the size and dignity which are the fit accompaniments of such an office come later.

Development of Spot Groups.—There is, however, no monotony in the characteristics of spot groups; they differ in appearance and in history quite as much as in size, and it soon becomes a most interesting occupation to watch their developments from day to day. Sometimes a considerable time will elapse, and no new spot will present itself; then on a sudden, on one and the same day, tiny new groups appear in every district of the spot zone. There will be little or nothing to distinguish these from each other at their first appearance, yet one will perhaps develop into a huge spot like that of November 1882, and the others will probably die out before two or three days have gone by. What can be the reason for the difference? Why should so many new groups appear simultaneously? Why should some disappear so soon and others attain so great a size? Many similar questions will be suggested by the various peculiarities which even an occasional

observer will remark in various spots; questions which certainly have a bearing on the nature not only of the spots, but of the Sun itself.

VARIOUS INQUIRIES AS TO SPOT CHANGES.—There are several inquiries which an amateur observer might well take up. First, it would be interesting to know on which side of the Sun most spots break out—on the visible or the invisible hemisphere, or whether they form about equally on both. A similar inquiry as to the place of disappearance might also be started, for both might have an important bearing on the question as to whether the Earth has any influence on the formation or dissolution of spots. But a more useful work still would be to record the dates when the greatest changes in shape and size took place, in order that these times might be compared with the times of the sudden deflections of the magnetic needle. Dr. Terby has suggested that the great auroræ and the great magnetic disturbances have coincided with the arrival of unusually large spots at the central meridian. Other observers consider that these phenomena coincide rather with the times of most rapid changes in the spots. The great magnetic storms of April and November 1882 are not decisive in the matter. The great November spot attained its greatest size and exhibited the most striking change just about the time of reaching the central meridian. At the time of the April storm there were three groups, two of them very large, which underwent constant and violent changes, so that it is not possible to definitely associate the magnetic disturbances with this or that phase of the development of either one of the groups. A careful series of observations undertaken to answer this question could hardly fail to throw some light upon it.

But though it is now thoroughly established not only

that there is a *general* correspondence between the forms of the sun-spot and magnetic curves for their respective periods, but also an intimate connection between *particular* solar outbursts and magnetic storms, there is an important gap in our information. It is not *all* large spots, nor even all spots undergoing violent changes, which have magnetic disturbances connected with them. Sometimes the magnetic trace will be as smooth and regular as possible when the state of the Sun would lead us to expect a marked irregularity. What makes the difference? No labour, however great, would be ill-spent if it could secure us an answer to this inquiry. Eye-observations, photography, the spectroscope should all be employed if by any means we may gain a hint of the true solution.

'The careful record of the dates when the groups seem to show the greatest changes and to attain the greatest size, and the positions they occupied at those dates, would be useful for the solution of another problem. Messrs. De La Rue and Stewart, in their valuable "Researches on Solar Physics," conclude that "the average size of a spot would appear to attain its maximum on that side of the Sun which is turned away from Venus, and to have its minimum in the neighbourhood of this planet." The results obtained from Carrington's observations, 1854–60, were certainly very remarkable, and, if similar results were obtained from a later series, the inference drawn from them would be very greatly strengthened.' Similar inquiries should be conducted for Jupiter, Mercury, and the Earth. The writer may frankly state that he finds it difficult to believe that any or all of the planets have any considerable determining influence on the *general* sun-spot period, but at the same time it is equally difficult to imagine that any observer could be long an attentive student of solar

phenomena without perceiving that there was *some* relation between the development of *individual* spots and the position of the planets.

'Another interesting inquiry connected with the determination, however rough, of the places of the spot-groups is the question as to whether outbreaks occur again and again in the same locality; whether there is evidence or no of seats of disturbance, from whence at various times spots spring up. Several careful observers are disposed to answer the question in the affirmative, whilst others are reluctant to admit a conclusion which would seem to point to a solid or quasi-solid condition of the solar nucleus.'

E. W. M.

APPENDIX I.

Date (Greenwich Mean Noon)	Inclination of Sun's Path = ι	Position Angle of Sun's Axis = P		Heliographic Co-ordinates of the Centre of the Sun			
				Latitude = D		Longitude = L	
1889	′	°	′	°	′	°	′
Jan. 1	+ 0·9	1	34	− 3	19	133	49
„ 11	+ 1·6	356	43	− 4	25	2	8
„ 21	+ 2·3	352	3	− 5	21	230	28
„ 31	+ 2·8	347	43	− 6	8	98	48
Feb. 10	+ 3·3	343	51	− 6	43	327	8
„ 20	+ 3·5	340	32	− 7	6	195	27
March 2	+ 3·7	337	48	− 7	15	63	44
„ 12	+ 3·8	335	43	− 7	11	291	58
„ 22	+ 3·8	334	18	− 6	53	160	7
April 1	+ 3·7	333	35	− 6	24	28	13
„ 11	+ 3·5	333	36	− 5	43	256	14
„ 21	+ 3·3	334	21	− 4	53	124	10
May 1	+ 3·0	335	50	− 3	55	352	1
„ 11	+ 2·6	338	2	− 2	50	219	48
„ 21	+ 2·1	340	55	− 1	41	87	32
„ 31	+ 1·5	344	23	− 0	29	315	12
June 10	+ 0·8	348	22	+ 0	43	182	51
„ 20	+ 0·1	352	42	+ 1	54	50	29

Date (Greenwich Mean Noon)	Inclination of Sun's path = ι	Position Angle of Sun's Axis = P		Heliographic Co-ordinates of the Centre of the Sun			
				Latitude = D		Longitude = L	
1889	′	°	′	°	′	°	′
June 30	− 0·6	357	13	+ 3	2	278	7
July 10	− 1·3	1	47	+ 4	5	145	46
„ 20	− 1·9	6	14	+ 5	1	13	27
„ 30	− 2·5	10	27	+ 5	49	241	10
Aug. 9	− 2·9	14	19	+ 6	27	108	56
„ 19	− 3·2	17	45	+ 6	55	336	46
„ 29	− 3·5	20	41	+ 7	11	204	39
Sept. 8	− 3·6	23	5	+ 7	15	72	34
„ 18	− 3·7	24	53	+ 7	6	300	33
„ 28	− 3·7	26	2	+ 6	44	168	35
Oct. 8	− 3·7	26	30	+ 6	11	36	38
„ 18	− 3·5	26	13	+ 5	26	264	44
„ 28	− 3·3	25	11	+ 4	32	132	51
Nov. 7	− 2·9	23	21	+ 3	28	1	0
„ 17	− 2·5	20	44	+ 2	18	229	10
„ 27	− 1·9	17	23	+ 1	4	97	22
Dec. 7	− 1·1	13	24	− 0	12	325	35
„ 17	− 0·3	8	55	− 1	29	193	50
„ 27	+ 0·5	4	8	− 2	43	62	7
1890							
Jan. 6	+ 1·3	359	15	− 3	51	290	25

The first column gives the inclination of the Sun's path to a parallel of declination. The inclination is positive when the Sun's declination is increasing, negative when it is diminishing. The second column gives the position angle of the N. end of the Sun's axis at noon, as measured from the true North in the direction N., E., S., W. The third and fourth columns give the heliographic latitude and longitude of the centre of the Sun's disc at noon. In computing the numbers in these columns the following elements have been assumed :—

Inclination of the Sun's equator to the ecliptic, 7°·15′.

Longitude of the ascending node of the Sun's equator, 74°·0′.

Time of the Sun's rotation on its axis, 25·38 days.

The meridian that coincided with the ascending node, January 1, 0^h, 1854, is adopted as the zero of longitude.

The first column remains the same for all years. The second and third columns will be substantially correct for Jan. 1, 1888,

18^h G.M.T., or for Jan. 1, 1890, 6^h G.M.T., and for every succeeding ten days; and the last column may be reduced to these dates by adding 140° 51′ for 1888, or by subtracting a similar quantity for 1890.

APPENDIX II.

The following observations were made of the positions of five spots seen on the Sun on August 6, 1885.

The telescope was firmly fixed and the diurnal motion of the Earth permitted to carry the Sun across the screen on which were drawn two straight lines A and B, intersecting at the centre of the screen, and each inclined at an angle of 45° to the equator. The times of the contact of the limbs of the Sun and of the several spots with the two wires, which are called A and B—A being the wire lying NE. and SW., and B that lying SE. and NW. —were estimated to the nearest tenth of a second by means of a chronometer beating half seconds. One advantage of the method is that it is not necessary to have actually the correct time; any good clock which is fairly steady in its rate will do perfectly well, as the determinations of position are purely differential.

The observations here recorded are not made in quite the best way. They were interrupted by clouds, and the telescope was slightly altered in declination between each series. If possible, the telescope should be kept rigidly clamped at the same declination from the first series to the last, and each series should begin as nearly as possible four minutes after the previous one. The seconds then will be the same for the same object in all the transits, and it becomes very easy to take the means and to detect a bad or erroneous observation. It will be more convenient also if the telescope is so set that the centre of the Sun passes a little north or south of the intersection of the wires. Six or seven spots can be observed pretty easily, if they are conveniently arranged, over both wires in the same transit; if there are more than seven, they may either be divided into two sets, and one set observed in one transit over both wires, and the other set in the next transit, likewise over both wires, or the entire number may be observed over one wire in the first transit, and over the other wire in the second transit, and so

on alternately for as many transits as it may be considered advisable to take. On a fine day, it can be easily arranged that the time from the commencement of one transit to the commencement of the next shall not exceed four minutes; and, as said above, there is a convenience in making it exactly four minutes. The reduction is effected in the same way whether the spots are observed over one wire in one transit, and over the other in the second, or over both wires in the same transit.

The first step in the reduction is to determine the inclination of the wire A to the normal to the Sun's path. This is readily found by dividing the time which the Sun takes in transiting over wire A by the time it takes in transiting over wire B, the result being the tangent of the angle required.

To this angle, which we call A, the angle ι, the inclination of the Sun's path to a parallel of declination, given in the table, must be added algebraically. $A + \iota$ then is the position angle of wire A from the north point. P, D, and L are taken out from the table, and log sin D and log cos D from a table of logarithms. The means of the times of transit, A_1 and A_2 of the first and second limbs over wire A, is taken to give the time, A_0, of the transit of the Sun's centre over wire A; and B_0, the time of its transit over wire B is found in a similar manner.

August 6, 1885.

	Wire A.			Wire B.		
	h	m	s	h	m	s
First limb . . .	12	8	46·23	12	9	3·80
Second limb . .	12	5	40·60	12	5	55·70
Difference . . .		3	5·63		3	8·10

$$A_2 - A_1 = 185^{s}\cdot63 \qquad B_2 - B_1 = 188^{s}\cdot10$$

$$\log A_2 - A_1 = 2\cdot26866$$

$$\log B_2 - B_1 = 2\cdot27439$$

$$\log \tan A = 9\cdot99427$$

$$A = 44^\circ\ 37'$$

$$\iota = -\ 0\ \ 3$$

$$A + \iota = 44\ \ 34$$

$$P = 13^\circ\ 11'$$

$$L = 351\ \ 59$$

$$D = +\ 6\ \ 16$$

$$\text{Log sin } D = +9\cdot03805$$

$$\text{Log cos } D = +9\cdot99740$$

The foregoing is common to all the spots observed on this day.

Object	Wire	First Transit	Second Transit	Third Transit	Mean	Spot—Sun over Wire A	Spot—Sun over Wire B
		h m s	h m s	h m s	h m s		
First Limb .	A	11 44 40·7	12 5 41·1	12 26 40·0	12 5 40·60		
First Limb .	B	11 45 0·6	12 5 55·9	12 26 50·6	12 5 55·70		
Spot I. . .	B	11 45 23·3	12 6 18·4	12 27 12·6	12 6 18·10		−71·65
Spot I. . .	A	11 45 33·8	12 6 33·5	12 27 32·7	12 6 33·33	−40·09	
Spot II . .	A	11 45 45·3	12 6 45·0	12 27 43·7	12 6 44·67	−28·75	
Spot III . .	A	11 45 51·1	12 6 51·3	12 27 50·0	12 6 50·80	−22·62	
Spot II . .	B	11 46 19·5	12 7 14·4	12 28 9·1	12 7 14·33		−15·42
Spot III . .	B	11 46 22·9	12 7 18·3	12 28 12·7	12 7 17·97		−11·78
Spot IV . .	B	11 46 53·5	12 7 49·5	12 28 43·7	12 7 48·90		+19·15
Spot V . .	B	11 46 56·6	12 7 51·9	12 28 46·2	12 7 51·57		+21·82
Spot IV . .	A	11 47 28·4	12 8 29·0	12 29 27·6	12 8 28·33	+74·91	
Spot V . .	A	11 47 35·4	12 8 35·0	12 29 33·1	12 8 34·50	+81·08	
Second Limb	A	11 47 46·1	12 8 46·9	12 29 45·7	12 8 46·23		
Second Limb	B	11 48 8·6	12 9 3·9	12 29 58·9	12 9 3·80		
Sun's Centre	A	11 46 13·4	12 7 14·0	12 28 12·85	12 7 13·42		
Sun's Centre	B	11 46 34·6	12 7 29·9	12 28 24·75	12 7 29·75		

The following reduction will explain itself for the most part. a is the position-angle of the spot from the NE. end of wire A, when the centre of the wires coincides with the centre of the Sun. The quadrant in which the spot is placed is found by remembering that when $a - A_0$ is positive, sin a will be positive, and that when $b - B_0$ is positive, cos a will be positive and *vice versâ*, a and b being the times of transit of the spot over the wires A and B respectively; θ is the position-angle of the spot from the N-point, and χ is the position-angle of the spot from the N extremity of the Sun's axis. In all cases position-angles are read in the direction N., E., S., W. The only point calling for notice is in the correction applied to the angle whose sine is $\frac{r}{R}$. This angle is not ρ, the true angular distance of the spot from the centre of the Sun's disc as measured on a great circle of the Sun itself, but $(\rho + \rho')$, ρ' being the angular distance of the spot from the centre of the disc as seen by the observer. (R) by which sin $(\rho + \rho')$ is multiplied in order to find ρ', is the radius of the Sun in minutes of arc. This of course varies at different times of the year, but no sensible error is introduced by adopting the mean value 16′ 2″, of which the log is 1·205. Dr. W. De

La Rue has, however, prepared tables which give log cos ρ and log sin ρ directly, when $\frac{r}{R}$ is known. The use of these tables and the substitution of four figure logarithms for five figures, the angles being taken out to tenths of a degree instead of to minutes, materially lightens the reduction, without depriving it of any real accuracy.

	Spot I.	Spot II	Spot III	Spot IV	Spot V
$a - A_0$	$-40^s{\cdot}09$	$-28^s{\cdot}75$	$-22^s{\cdot}62$	$+74^s{\cdot}91$	$+81^s{\cdot}08$
$b - B_0$	$-71\ {\cdot}65$	$-15\ {\cdot}42$	$-11\ {\cdot}78$	$+19\ {\cdot}15$	$+21\ {\cdot}82$
Log $(a - A_0)$	$-1{\cdot}60304$	$-1{\cdot}45864$	$-1{\cdot}35449$	$+1{\cdot}87454$	$+1{\cdot}90891$
Log $(b - B_0)$	$-1{\cdot}85522$	$-1{\cdot}18808$	$-1{\cdot}07115$	$+1{\cdot}28217$	$+1{\cdot}33885$
Difference	$+9{\cdot}74782$	$+0{\cdot}27056$	$+0{\cdot}28334$	$+0{\cdot}59237$	$+0{\cdot}57006$
Log tan A	$9{\cdot}99427$	$9{\cdot}99427$	$9{\cdot}99427$	$9{\cdot}99427$	$9{\cdot}99427$
Diff = Log tan a	$+9{\cdot}75355$	$+0{\cdot}27629$	$+0{\cdot}28907$	$+0{\cdot}59810$	$+0{\cdot}57579$
a	$209^\circ\ 33'$	$242^\circ\ 6'$	$242^\circ\ 48'$	$75^\circ\ 50'$	$75^\circ\ 8'$
A + ι	44 34	44 34	44 34	44 34	44 34
Sum = θ	254 7	286 40	287 22	120 24	119 42
P	13 11	13 11	13 11	13 11	13 11
$\theta - P = \chi$	240 56	273 29	274 11	107 13	106 31
Log $(b - B_0)$	$1{\cdot}85522$	$1{\cdot}18808$	$1{\cdot}07115$	$1{\cdot}28217$	$1{\cdot}33885$
Log $(B_2 - B_1)$	$2{\cdot}27439$	$2{\cdot}27439$	$2{\cdot}27439$	$2{\cdot}27439$	$2{\cdot}27439$
Difference	$9{\cdot}58083$	$8{\cdot}91369$	$8{\cdot}79676$	$9{\cdot}00778$	$9{\cdot}06446$
Log sec a	$0{\cdot}06052$	$0{\cdot}32982$	$0{\cdot}33999$	$0{\cdot}61129$	$0{\cdot}59079$
Log 2	$0{\cdot}30103$	$0{\cdot}30103$	$0{\cdot}30103$	$0{\cdot}30103$	$0{\cdot}30103$
Sum = Log $\frac{r}{R}$ = Log sin $(\rho + \rho')$	$9{\cdot}94238$	$9{\cdot}54454$	$9{\cdot}43778$	$9{\cdot}92010$	$9{\cdot}95628$
Log (R)	$1{\cdot}205$	$1{\cdot}205$	$1{\cdot}205$	$1{\cdot}205$	$1{\cdot}205$
Sum = Log ρ'	$1{\cdot}14738$	$0{\cdot}74954$	$0{\cdot}64278$	$1{\cdot}12510$	$1{\cdot}16128$
$\rho + \rho'$	$61^\circ\ 8'$	$20^\circ\ 31'$	$15^\circ\ 54'$	$56^\circ\ 18'$	$64^\circ\ 43'$
ρ'	14	6	4	13	14
ρ	60 54	20 25	15 50	56 5	64 29
$\frac{r}{R}$	$0{\cdot}8758$	$0{\cdot}3504$	$0{\cdot}2740$	$0{\cdot}8320$	$0{\cdot}9042$
Log cos χ	$-9{\cdot}68648$	$+8{\cdot}78360$	$+8{\cdot}86301$	$-9{\cdot}47127$	$-9{\cdot}45377$
Log cos D	$9{\cdot}99740$	$9{\cdot}99740$	$9{\cdot}99740$	$9{\cdot}99740$	$9{\cdot}99740$
Log sin ρ	$9{\cdot}94140$	$9{\cdot}54263$	$9{\cdot}43591$	$9{\cdot}91900$	$9{\cdot}95543$

	Spot I	Spot II	Spot III	Spot IV	Spot V
Sum = Log I	−9·62528	+8·32363	+8·29632	−9·38767	−9·40660
Log sin D	+9·03805	+9·03805	+9·03805	+9·03805	+9·03805
Log cos ρ	9·68694	9·97182	9·98320	9·74662	9·63425
Sum = Log II	+8·72499	+9·00987	+9·02125	+8·78467	+8·67230
I	−0·4220	+0·0211	+0·0198	−0·2442	−0·2550
II.	+0·0531	+0·1023	+0·1050	+0·0609	+0·0470
Sum = Sin λ	−0·3689	+0·1234	+0·1248	−0·1833	−0·2080
λ = Heliographic Latitude .	−21° 39′	+7° 5′	+7° 10′	−10° 34′	−12° 0′
Log sin χ	−9·94154	−9·99920	−9·99884	+9·98009	+9·98170
Log sin ρ	9·94140	9·54263	9·43591	9·91900	9·95543
Log sec λ	0·03177	0·00333	0·00341	0·00743	0·00960
Sum = Sin (L − *l*)	−9·91471	−9·54516	−9·43816	+9·90652	+9·94673
L − *l*	− 55° 15′	− 20° 32′	− 15° 55′	+ 53° 44′	+ 62° 12′
L	351 59	351 59	351 59	351 59	351 59
l = Heliographic Longitude .	47° 14′	12° 31′	7° 54′	298° 15′	289° 47
Measured Area	3½	3·1	3·1	5⅔	2·1
Log Measured Area	6·52288	6·49136	6·49136	6·75333	6·32222
Log $2\pi r^2$	4·83224	4·83224	4·83224	4·83224	4·83224
Difference	1·79064	1·65912	1·65912	1·92109	1·48998
Log cos ρ	9·68694	9·97182	9·98320	9·74662	9·63425
Diff. = Log Reduced Area . .	2·10370	1·68730	1·67592	2·17447	1·85573
Area in Millionths	127	49	47	149	72

The areas of the spots were measured by the number of squares and parts of a square which they covered on the screen, the side of each square being 0·05 inch. The radius of the Sun being 5·2 inches, it was 104 on the scale of which the side of a square was a unit, and log $2\pi r^2$ was therefore 4·83224. As it was desired that the resulting reduced area should be expressed in millionths of the Sun's hemisphere, and in order to avoid negative characteristics, the characteristic of 'log measured area' has been increased by 6 (= log 1,000,000). Any other scale might have been adopted; a millimètre scale is a very convenient one, and good cross-ruled millimètre paper can be readily procured.

CHAPTER IV.

THE MOON.

INSTRUMENTAL REQUIREMENTS OF SELENOGRAPHY.—Perhaps no branch of observational astronomy offers so many attractions, and, at the same time, demands so little in the shape of apparatus, as the study of the Moon's surface. Work of permanent value may be accomplished with very moderate telescopic means. The possessor of a good $3\frac{1}{2}$ in. achromatic, or of a silver-on-glass reflector of 5 or 6 in. aperture, will not only find Lunar observation a never-failing source of interest, but, if he brings an average amount of enthusiasm and intelligence to bear upon it, may, even in these days of giant telescopes, do substantial service to selenography. To point out some of the principal Lunar features to amateurs of this description, and to direct their attention to details worthy of special notice, is the purpose of the present chapter.

LUNAR FORMATIONS.—Though Kepler's dictum respecting the Moon's visible surface—'do maculas esse maria, do lucidas partes esse terram,' cannot, in the light of modern observation, be accepted as literally true, the distinction, manifest to the naked eye, between the bright and dusky areas is certainly due to an actual difference in their physical character, and selenographers still apply the term Maria or 'Seas' to the latter, which probably represent ancient sea beds, or, at any rate, alluvial deposits,

while they regard as undoubted land surfaces the more elevated and diversely constituted regions which constitute the brighter remainder. On each of these contrasted areas, but far less plentifully developed on the Maria than elsewhere, we meet with a number of circular or subcircular formations, differing widely in size, classed as walled-plains, ring-plains, craters, &c., which, under small magnification, seem to bear a certain resemblance to volcanoes, an analogy, however, which to a great extent breaks down when they are studied with high powers. Mountain chains, ranges of hills, isolated peaks, valleys, ridges, long furrows (termed rills), and other features are also more or less abundantly found in every part of the Moon, together with minute details which include true analogues to terrestrial volcanoes.

MARIA OR 'SEAS.'—These apparently monotonous dark grey tracts contain many objects which deserve attention, especially the innumerable *ridges* which traverse them. It is a curious and suggestive circumstance that in many instances these features seem to follow the trend of the coastline. This obvious tendency is especially well shown by those which border the Mare Serenitatis and Mare Humorum. A magnificent view of the latter is obtained when the morning terminator passes through Vitello and Gassendi. There appears to be a very distinct connection between ridges and small craters in all parts of the Moon, more apparent, however, on the surface of the seas than elsewhere, which would form an interesting subject for further investigation. Many of the seas, especially under a high angle of illumination, exhibit differences of tint in various parts which are certainly not wholly due to the presence of ridges or visible inequalities on their surface. With high powers and the best atmospheric conditions they

often seem to be covered with minute points of light and a network of streaks far too delicate to represent in a drawing. This appearance may be attributable to minor irregularities of the surface or to actual differences in its tone. If the Earth were viewed from an equally distant standpoint, the varieties of tint due to natural and artificial causes would probably produce a very similar effect.

Some of the Maria show not only local variations in brightness but undoubted differences in colour extending over wide areas. Mädler asserts that the central region of the Mare Serenitatis is of a decided light green tinge, while the Mare Humorum is of a similar but darker tone. The Mare Crisium is also green, while the Mare Frigoris exhibits a dirty yellowish-green tint. The Palus Somnii (east of Proclus) is said to be of a peculiar golden-brown colour, and the Mare Imbrium brownish-yellow with a suspicion of green. The tint in the last instance is perhaps more generally noticeable than in the other cases cited. The colours observed may possibly be purely subjective phenomena, though their limitation to certain regions seems to negative this supposition. In any case the matter deserves more consideration than has hitherto been bestowed upon it, and should be diligently followed up.

The following is a list of the Lunar Seas and Grey Plains.

(The letters on the left refer to corresponding letters cn the Index Map.)

A. Mare Imbrium	Sinus Iridum N. lat. 45°, E. long. 30°).
B. „ Serenitatis	„ Roris (N. lat. 55°, E. long. 50°).
C. „ Crisium	„ Æstuum (N. lat. 12°, E. long 8°).

D. Mare Nectaris	Sinus Medii (N. of Réaumur. Near the centre of the visible disc).
E. „ Fœcunditatis	Palus Nebularum (N. lat. 37°, W. long. 3°).
F. „ Nubium	„ Somnii (N. lat. 14°, W. long. 45°.
G. „ Humorum	„ Putredinis (N. lat. 27°, W. long. 2°).
H. Oceanus Procellarum	Lacus Somniorum (N. lat. 37°, W. long. 34°).
N. Mare Frigoris	„ Mortis (N. lat. 45°, W. long. 30°).
T. „ Tranquillitatis	Mare Humboldtianum (on NW. limb in lat. 60).
W. „ Vaporum	„ Smythii (on W. limb extending from N. lat. 6° to S. lat. 8°).

Mare Australe (on SW. limb extending from S. lat. 36° to S. lat. 54°).

Walled Plains, Ring Plains, &c.—There is ample scope for useful work in examining the details of these formations, much of it being well within the power of small apertures. The shape of the borders, the position of passes, valleys, spurs, large depressions, &c., may all be drawn and studied by means of ordinary telescopes with a view to rectify mistakes and omissions in existing maps. The interiors of these immense circumvallations present likewise many points of interest to the observer, including, as some of them do, an epitome of almost every type of lunar object within a comparatively small compass. Lofty isolated peaks, mountain chains, ridges, low rounded hills, craters of various sizes, crater-cones, clefts, dark and light markings, not unfrequently exist on the floor of a single formation. In Ptolemäus we find a number of curious saucer-

shaped depressions visible only when near the terminator. In Plato, Fracastorius, Archimedes, and other walled plains, a host of craterlets, crater-cones, and spots is associated with a network of delicate light streaks. In Gassendi, in addition to the complex central mountain and numberless minor heights, is a most remarkable and difficult system of rills. In Mersenius we have the peculiarity of a convex floor crossed by a long crater-row. The magnificent object Alphonsus, besides many other types of lunar features, contains some dusky spots, on one of which, close to the east border, is situated a crater-cone pertaining to a class which will be noticed under its proper head. Again, some of these formations (Beaumont and Stadius, for example) appear to be closely pitted with minute craters, while others seem to be entirely void of detail. In certain cases where these enclosures abut on the Maria or Seas, the side nearest the sea is either partially or completely ruined, a state of things which is particularly noticeable in the case of Fracastorius on the south side of the Mare Nectaris, in Le Monnier on the west side of the Mare Serenitatis, in Hippalus, Lee, and Doppelmayer bordering the Mare Humorum, and in Pitatus on the south side of the Mare Nubium. The breached north border of Fracastorius is seen best under evening illumination, when two or more large mounds and a number of small craters can be traced on the site once occupied by the wall. The position of the destroyed borders of Doppelmayer and Le Monnier may likewise be easily detected near lunar sunrise or sunset in the form of broad low ridges covered with the dark alluvium of the neighbouring Seas. In addition to these, instances are not wanting of formations being so completely destroyed or submerged that only a broken ring or a mere scar on the surface of the Maria at present exists

to indicate their position, as, for example, Flamsteed, the so-called Harbinger Mountains north-west of Aristarchus, Stadius, Bonpland, Fra-Mauro, Doppelmayer C, Egede, and what was probably once a considerable walled plain between Seleucus and Otto Struve.

✓CRATERS.—Under this generic term may be included a large number of circular formations widely differing in size and other characteristics. A superficial examination with low powers suggests an analogy, as is also the case with many of the ring-plains, to terrestrial volcanoes, while a closer scrutiny renders the similitude less apparent. Proclus, 18 miles in diameter; Aratus, 8 miles in diameter; Conon, 11 miles in diameter; and Carlini, 5 miles in diameter, may be taken as brilliant and interesting examples of the isolated class of craters, while the mountain-borders, the floors, the summits and slopes of the walled- and ring-plains afford instances in abundance of the association of these objects with the larger lunar formations. We frequently have crater-ring encroaching on crater-ring, as in the case of Thebit, where the larger crater A on the summit of the east wall has in its turn a smaller crater on its own east wall. Like other enclosed formations on the Moon, the craters very often contain central mountains. Some of these are excellent tests for the definition of the telescope —as, for instance, the central peaks of Hortensius, Bessarion, and that of the small crater just referred to on the east wall of Thebit A.

✓ CRATERLETS, CRATER-PITS, CRATER-CONES.—As in the case of the so-called craters, it is very difficult to define with precision the special characters which distinguish a number of the objects classed under the head of craterlet. The term, now usually confined to the smaller class of craters, is needless and misleading, pointing to a distinc-

tion without a real difference. Between the craters and the crater-pits there are, however, undoubted and well-marked dissimilarities, such as the absence in the latter of visible borders and their comparative shallowness, peculiarities which entitle them to be placed in a distinct category. Small apertures unfortunately break down among the smallest types both of craters and crater-pits; countless numbers of them, scarcely exceeding a few hundred yards in diameter, can only be barely glimpsed under the best optical and atmospheric conditions. There is ample work to be done, however, in observing and cataloguing the larger objects of this class, in noting their position and their apparently intimate connection with ridges, clefts, and other lines of disturbance, which may be satisfactorily accomplished with telescopes of moderate dimensions. Their obvious tendency to a linear arrangement, exhibited in many regions, and their remarkable development on the slopes and in the neighbourhood of larger formations, are all matters requiring further investigation, which, when thoroughly worked out, may possibly throw much needed light on the past history of our satellite, even if such an examination does not, as it possibly may, demonstrate the existence of forces still in activity. One of the best examples of a crater-row is that north-west of Copernicus. If it is examined about the time when the morning terminator bisects this magnificent ring-plain, it will be seen to consist of a series of fourteen or fifteen very irregularly-shaped craters, many of them confluent and evidently bounded by lofty walls. The region east of this row is pitted with innumerable craters of the minutest type.

Crater-cones are among the most interesting of minute lunar objects, as they undoubtedly present a closer resemblance to terrestrial volcanic vents than any others.

They seldom exceed two miles in diameter at the base, and the crater, which occupies their summit, is usually very small and difficult to detect. Probably nearly all the minute faint white spots which figure on the floors of Plato, Archimedes, Fracastorius, and other formations, are crater-cones, though only comparatively few of them have as yet been actually distinguished as such. Unlike the majority of craters and crater-pits, the crater-cones often retain their visibility under all angles of illumination, appearing as delicate nebulous light specks under a high sun. Those on the floor of Plato have been specially studied and shown to undergo variations in visibility hard to account for except on the supposition that actual changes occur, a circumstance which, when taken in connection with their analogy to volcanoes, adds in no small degree to their interest. Dr. Klein, of Cologne, has recently called attention to certain crater-cones situated on small dark or smoky-grey areas found here and there on the Moon which, as probably representing active volcanic vents, he urges should be diligently observed. Examples of these objects will be found (1) West of a ridge extending from Beaumont to Theophilus and about midway between the two. (2) In the Mare Vaporum south of Hyginus. (3) In the interior of Werner, near the north wall. (4) Under the east wall of Alphonsus on the floor. (5) On the south side of the floor of Atlas. These dusky spots can be easily seen in small telescopes and even traced in photograms, but large apertures are needed to observe the cones which stand upon them to advantage. The attention of beginners might well be confined to the careful delineation of the dark areas, as it is not improbable, if they are due to the *ejecta* from volcanoes, that changes in their shape and extent may from time to time be de-

tected. Dr. Klein has also quite lately observed some mysterious dark spots, first noticed by Schmidt, visible under a high light and in good air between Copernicus and Gambart. He describes part of this region as perforated like a sieve with the smallest class of craters (not more than 500 feet in diameter). He has identified and mapped a number of these minute objects which should be diligently watched with large apertures. A moderately bright crater, surrounded by a grey nimbus, standing a little south-west of Copernicus, may be classed with these suspicious features. It is easily seen at and about full moon.

Clefts or Rills.—These remarkable and as yet inexplicable furrows rank among the most delicate of lunar features. Their length varies from 10 or 12 to 300 miles or more (as in the case of the great Sirsalis rill), their width from 500 to upwards of 4,000 yards, and their depth from 100 to 400 yards. They exhibit in the telescope a gradation from coarse chasms, easily visible with low powers, to delicate striæ requiring the most powerful optical means and the best atmospheric conditions to be glimpsed at all. They are found in almost every part of the Moon, but more frequently on the floors of the larger formations and on the borders of the 'seas,' seldom occurring in the central portions of these great alluvial tracts. To observe the details of the rills and their local widenings and contractions to advantage, and to trace the course of the more delicate examples, a power of not less than 350 or 400 is necessary in exceptionally favourable observing weather.

About twenty years ago Schmidt estimated the number of rills to be 425, yet, though he included many objects which cannot strictly be classed as such, this number, were a complete catalogue to be now prepared, would pro-

bably be at least doubled. Fresh rills and extensions of those already known are constantly being detected, and, so strange are some of the circumstances relating to their discovery in regions which have been formerly thoroughly scanned, and to their apparent disappearance in other places where they were once seen, that there are good grounds for a suspicion that they either undergo temporary obscuration, or that new furrows are occasionally formed and old ones destroyed by the operation of some unknown cause. Though to do good work in this branch of Selenography requires a large aperture, a favourable atmosphere, and a trained eye, yet new rills and prolongations of old ones are from time to time brought to light by means of 'common telescopes.' So much depends on the state of the air and the conditions of illumination that, however humble his optical means, the observer should always make a diligent search for them in every district he examines. Occasionally, though difficult to detect at other times, they may be seen as faint light streaks under a high angle of illumination in a comparatively small instrument. As cases in point may be mentioned the fine rill, running nearly parallel to the straight wall, north of Birt in the Mare Nubium, the great Hyginus cleft, portions of the Ariadæus rill, and that which crosses the Alpine valley. These and many others may be readily seen at or about full moon with a 3½ inch achromatic. Much remains to be done in tracing the course of even the wider and more palpable rills, in noting the craters and other objects by which or through which they pass, in recording local variations in their breadth, and other details which will often be found to be within the capacity of ordinary telescopes.

E. L. Trouvelot, of Meudon, has recently called attention to a remarkable phenomenon which he has observed

in connection with certain rills when near the terminator—viz. extremely attenuated threads of light on their sites and on their apparent prolongations, as if narrow walls of rock were sometimes associated with them. He has remarked this appearance in Eudoxus, crossing the southern part of the floor and extending nearly from wall to wall; in connection with the prominent rill running from the north side of Burg to the west of Alexander; in a short rill from west side of Herodotus to the south border of Aristarchus, and in other instances. Observers should endeavour to confirm these interesting observations, which would appear to have an important bearing on the conformation of rills. Apparent prolongations of them in the form of rows of rocks and low mounds are very common and should be carefully noted.

The following list of some of the principal rills and rill-systems has been prepared for the use of amateurs who do not possess a map or catalogue of these objects. It relates to those which may, in part at least, be observed with moderate apertures, and which are likely to be detected without much difficulty. The rills are classed under the head of the formations in their immediate neighbourhood.

List of Rill-Systems.

North-West Quadrant.

Triesnecker.—In the region lying west of this formation, between Rhæticus on the south and the neighbourhood of Hyginus on the north, there is a remarkable network of rills; some of them, especially that from Rhæticus A. to NW. side of Triesnecker, and a rill running E. of this from near Rhæticus, are easy objects. An accurate representation of the system is still wanting.

Hyginus.—One of the most prominent and remarkable rills passes through this crater from a small crater north of Agrippa.

Its coarser portions may be seen with a 2-in. aperture. It exhibits in places (especially that part of it lying north-east of Hyginus) cup-shaped expansions and great irregularities in breadth, which should be studied with high powers. On favourable occasions it may be traced through Hyginus, the raised banks, which here border it, appearing as fine bright lines while the interior of the great crater-pit is in shadow. The whole district between the northern arm of this object and Triesnecker is furrowed with delicate rills, all more or less difficult.

Sabine and Ritter.—From a ridge south of Sabine two easily-seen parallel rills run in a westerly direction nearly on the lunar equator, with a shorter intermediate rill near their western ends. On the east of Ritter, between it and Dionysius, is a probable extension of this system to the great Ariadæus rill and to a branch from it near its western end; while in the region west of Julius Cæsar are a number of more or less delicate rills, skirting the eastern side of the Mare Tranquillitatis, and an occasionally distinct rill running from near Sosigenes *a* to Arago.

Ariadæus.—The great rill, discovered in 1792, running from mountains near the bright crater Ariadæus and extending to the region between Boscovich and Hyginus, is one of the finest and most conspicuous objects of its class. The western portion of it may be best seen when the morning terminator passes a little east of Agrippa. It is an unusually interesting example of a ril traversing a rough hilly region and encountering mountains and other obstacles in its course.

Plinius.—There is a fine rill-system north of this formation, which may be observed to advantage when the eastern wall of Julius Cæsar is on the morning terminator, though the principal and easiest member of it, viz. that nearest to Plinius and which runs up to Dawes, is conspicuous a few hours after sunrise and may be seen with a low power. It is in part a crater-rill. There are two other rills running nearly parallel to the last, one of which originates on the north and the other on the south of the Prom. Acherusia, the extreme western end of the Hæmus range. Both these objects are somewhat difficult, but have been seen with an aperture of 4 in.

Cauchy.—On the south-east of this bright little crater there is an easy rill.

The Apennines.—Between N. lat. 23° and 29° there is a very complicated and interesting system composed in part of closely-parallel rills. Many of them follow the trend of the Apennine escarpment and ultimately ramify among a range of hills lying a few miles to the east of the principal chain. A few of them are easily seen; but the majority are difficult. They are best observed under evening illumination, as under morning light they are more or less involved in the pronounced shadows of the mountains.

Sulpicius Gallus.—On the Mare Serenitatis at the foot of the Hæmus range, north-east of this brilliant crater, there is a short rill which is an easy object under morning illumination.

Littrow.—A long rill, difficult to see in its entirety, runs from near Dawes, passes east of Littrow, and terminates between Römer and Le Monnier. There are several other rills, all more or less delicate, in the hilly country on the west border of the Mare Serenitatis.

Römer.—A long rill from N. side of Römer to Bond B.

Posidonius.—This magnificent ring-plain includes a fine rill which runs in an axial direction on the west of the central crater A. There is another rill at right angles to it on the south side of the floor, which at sunset is an easy object.

Charcornac.—Two closely-parallel rills traverse this formation in the same direction as the principal rill in Posidonius.

The Great Alpine Valley.—A fine rill, which is not difficult under low evening illumination, runs from near the upper or north-west end of the valley in an easterly direction. Another rill, which is less easily detected, crosses the valley nearly at right angles to its axis at a point about midway between its extremities. At or about full moon, however, it may be traced as a white line on the floor of the valley with small apertures.

Burg.—A distinct rill runs in an easterly direction from N. side of this ring-plain.

Atlas.—A rill crossing the interior of this formation a little west of the central mountains is not a difficult object. There is

a second rill running parallel to the east wall and joining the last south of the centre which is less obvious.

Geminus.—There are two rather coarse rills in the interior of this fine ring-plain, one running parallel to the inner foot of the SE. wall and the other to that of the NW. wall.

North-East Quadrant.

Gay-Lussac.—This small ring-plain is traversed from North to South by two parallel rills or crater-rows. There is also a remarkable rill-like valley extending in a south-easterly direction from the eastern border of Gay-Lussac.

Lohrmann and Hevel.—The surface west of Lohrmann is furrowed by a number of short rills and crater-rows which require mapping. A curious winding rill, consisting in part of confluent craters, runs from the south-east wall of Hevel to Riccioli. Within Hevel there are four rills on the southern half of the interior. One of these runs from the western wall to a point a little south of a crater on the SE. border, and is crossed a little S. of the central mountain by a rill from the SW. border. These objects are not difficult when libration and other conditions are favourable.

Archimedes.—Between the hilly region south of Archimedes and the Apennines are several rills, two of which, running in a south-westerly direction, are not difficult under evening illumination.

Aristarchus and Herodotus.—The great serpentine valley associated with Herodotus is undoubtedly one of the most noteworthy objects on the visible surface of the moon. Though termed a valley it is, except as regards its dimensions and its winding course, very similar in character to the true rills. Its tortuous progress from its commencement at a wide cross valley in the mountains east of Herodotus to its outlet in the interior of this formation cannot be well traced as a whole till the east longitude of the morning terminator is about 58°, otherwise the shadows of neighbouring highlands will partially obscure its broader end. There is another remarkable but short rill which branches out from the west side of the valley near its embouchure and ultimately divides into two branches, one branch running

close to the west border of Herodotus and the other extending to the east wall of Aristarchus. This object is well seen when the east wall of Herodotus is on the morning terminator. There are many delicate rills and curious winding valleys in the hilly district north of Aristarchus, but they are mostly difficult features.

Cardanus and Kraft.—A fine rill connects these formations. It is a striking feature when the eastern walls of these ring-plains are on the morning terminator, and is an interesting example of a rill bordered by banks which are visible as bright lines at sunrise.

South-East Quadrant.

Alphonsus.—Two distinct and nearly parallel rills traverse this formation from North to South, crossing the central region. The more westerly of the two is at its northern end a crater rill.

Arzachel.—There is a curious winding rill on the western side of the interior between the large crater on the floor and the foot of the wall. It is an easy object.

Parry, Fra Mauro, and Bonpland.—These objects are crossed by a rill running in a meridional direction. That portion of it which is included in Fra Mauro is easily traced at suitable times. The southern section skirts the eastern side of Parry. There is another rill, nearly parallel to the last within Bonpland.

Gassendi.—Upwards of twenty rills exist on the floor of this grand object, but, with two or three exceptions, they are all very delicate and difficult.

Sirsalis.—This small double formation gives its name to one of the longest lunar rills, which is probably not much less than 300 miles in length. For a great part of its course it is not difficult. Towards its southern end it can be traced through a small ring-plain south of Crüger (De Vico *a*), beyond which it becomes broader and deeper till it is apparently lost at a ridge in the neighbourhood of Byrgius, though Schmidt has traced it still farther in a southerly direction. In the region east of Crüger and De Vico *a* there is another magnificent rill probably connected with the Sirsalis system.

Pitatus and Hesiodus.—The rill running in an easterly direction from the north side of Hesiodus towards Capuanus is

an easy object, especially that portion of it which lies in the Mare Nubium. Its progress through the mountainous country between Mercator and Capuanus is more difficult to trace.

Ramsden.—This ring-plain is associated with one of the most remarkable rill-systems on the moon. Schmidt, in a special map, shows fourteen distinct rills in its immediate neighbourhood. Three of these running from the mountain mass north of Ramsden to the border and two longer rills on the opposite side of the formation, following a south-westerly course, are not difficult.

Birt.—East of the well-known straight wall is an easy rill originating in rising ground north of Birt and running up to the foot of its eastern wall. The gradual widening of the sloping sides of this rill, as it traverses the high ground near its northern end, reminds one of a railway cutting seen from above. There is another rill commencing at the same hill and passing more to the east of Birt, which is not difficult under evening illumination. I have seen it most perfectly when the straight wall was on the evening terminator.

Hippalus.—A very remarkable group of nearly parallel rills is found in the neighbourhood of this formation. Most of them originating between Campanus and the western side of the Mare Humorum, follow roughly the curvature of this border. The most obvious member of the system traverses Hippalus and passes on northwards towards Agatharchides. On the south of the ridge connecting Campanus and Hippalus four of these parallel clefts in close contiguity are tolerably easy objects, the most westerly of them, crossing a crater on this ridge and a second crater north of the ridge, can be traced to some mountains west of Agatharchides. Between it and Hippalus are two shorter clefts. I have seen all these objects on an average night with a power of 200 on a 4 in. achromatic.

Mersenius and Cavendish.—The eastern side of the Mare Humorum, south-east of Gassendi, and the very interesting region south of Mersenius and Cavendish, includes perhaps a larger number of rills than any other district of equal area on the moon. They form apparently a connected system, though, except as regards a few of them, a connection has not as yet been actually

traced. The broad coarse rill running from the mountain mass south of Gassendi to the south-west side of Mersenius is a very easy object, but not so the intricate system crossing the Mare on the west of it, all the members of which are more or less difficult, except the most westerly; this when near the morning terminator is comparatively prominent. On the convex floor of Mersenius is a noteworthy crater-row running in a meridional direction, the component craters being connected by a rill. It is interesting to observe these minute objects on the crest of the floor gradually coming into sunlight when the eastern wall is on the morning terminator. Search should be made for a rill which crosses the northern quarter of Mersenius nearly at right angles to the crater-row. This was first seen on November 12, 1883, with a power of 350 on a 8½ in. Calver, but has been observed since, under bad atmospheric conditions, with a much lower power.

Schickard.—The floor of this immense circumvallation includes some short clefts in connection with the craters and ridges situated on the east and south portions of the interior.

South-West Quadrant.

Almanon and Abulfeda.—The remarkable crater-rill forming a tangent to the walls of these formations and its westward prolongation in the shape of a row of large craters and depressions is an object of special interest.

Rhæticus.—A prominent rill crosses the northern portion of the floor and is prolonged in an easterly direction to Réaumur.

Réaumur.—West of Réaumur is a fine though short rill.

Goclenius.—This formation and the Pyrenean region north-east of it include a number of rills, most of which are easy objects. One of them after crossing the floor of Goclenius extends northwards for many miles. These rills are best seen about the time when the morning terminator is on the eastern wall of Guttemberg.

Fracastorius.—A winding rill traverses the central part of the floor of this formation from east to west. It is perhaps best seen under low evening illumination. A difficult object.

Petavius.—The wide deep rill running from the large central mountain of Petavius to its south-eastern border is one of the easiest objects of its class, and may readily be seen with an aperture of two inches or even less. Observers should endeavour to trace it beyond the inner wall and ascertain how far it is prolonged toward the south. There is another more difficult rill on the west side of the floor running nearly parallel to the border.

Jansenn.—A rill-like valley, easily seen with 2-in. aperture, crosses this great enclosure from the north-west of Lockyer to Fabricius, where it bends abruptly towards the west and passes between this formation and a smaller ring-plain on the west of it.

VALLEYS.—Innumerable objects which may be classed under this head are to be found in almost every part of the lunar surface, many of them being extremely delicate and at times scarcely distinguishable from rills. There are others, however, which, from their size and other characteristics, call for special notice. Among them are the following:—

The Great Alpine Valley.—This magnificent object, nearly 100 miles in length and varying from three to six miles in breadth, connects the Mare Frigoris with the Mare Imbrium. Shallow and narrow at its upper or northern end, it gradually increases in depth and width as it proceeds southwards till it encounters the great mountain barrier of the Alps, through which it passes by two very constricted defiles with a remarkable intermediate oval expansion partially surrounded by 'a noble amphitheatre' of towering heights. The details of the valley will repay careful study under every condition of illumination, but especially near sunset, when the neighbourhood of the upper or northern end presents a magnificent spectacle. A rill, which can be traced as a delicate

white line on the floor at or near full moon, crosses the valley about midway, and there are some curious dark spots (probably craterlets) in the interior, below the cliffs forming its south-western border, which should be examined under different solar altitudes.

The Rheita Valley.—Commencing on the eastern side of Rheita, this valley extends for a great distance towards the south-east. It is contracted midway by cliffs, but ultimately expands to a breadth of 20 miles or more. Neison gives its length as 187 miles.

The Reichenbach Valley.—North of the last is another remarkable and somewhat similar valley extending from the west side of Reichenbach nearly up to the north border of Rheita.

The Great Valley south-east of Ukert, classed by Schmidt among the rills, runs from north-east to south-west for a distance of 83 miles. According to Mädler, it is nearly 13,000 feet wide at its southern end and narrows to about 5,000 feet at its northern extremity.

Good examples of the simpler class of rill-valleys will be found in the narrow valley immediately south of Guerike and in another like object extending towards the south-east from the border of Gay-Lussac.

The Maria and many of the larger formations also furnish instances of long winding valleys intersecting their borders, and many lunar highlands are crossed by curious branched valleys well worth attention; in short, there is no end to the number of these features, though they differ widely in size and exhibit other dissimilarities.

FAULTS.—In the sense that the term 'fault' is used in geology, it is of course impossible to say whether the evident dislocations with corresponding depressions and elevations of the neighbouring surface, frequently

observed on the moon, resemble in their details those so plentifully found among the various terrestrial formations; yet the so-called lunar faults, like those on the earth, are undoubtedly fissures or cracks due to movements which have taken place in the solid crust. Unlike the great majority of terrestrial faults, however, all superficial traces of which have been destroyed either by subsequent deposits or by denudation, many of those on the moon manifest themselves at the surface by sudden interruptions in level, which, if looked for when near the terminator, may be readily detected. By far the finest instance of a lunar fault is that called *the straight wall*, or sometimes 'the railroad,' which lies on the western side of the Mare Nubium, east of Thebit, and between that formation and Birt. It is traceable under almost every condition of illumination, but to appreciate its 'downthrow,' or the sudden drop of six or seven hundred feet in the surface of the Mare, the neighbourhood should be scrutinised soon after lunar sunrise, say when the morning terminator passes between Birt and Nicollet; while to see its brilliant eastern escarpment, the actual face of the fault, it must be observed near sunset, or when the wall itself is on the evening terminator. In many cases, though the course of a fault cannot be traced in its entirety under suitable illumination by a well-marked shadow, yet the existence of such a feature in some regions may be inferred from the dislocation of neighbouring objects. This is the case in the well-known walled-plain Plato, where there are evident signs of a line of disruption (shown by breaks in the north-west and south-east walls), extending obliquely across the interior, though the indications of it on the floor are barely distinguishable. The investigation of the direction of these lines of fracture is of great importance, as tending to throw

light on the past history of the districts where they are found.

MOUNTAIN RANGES.—(a.) *The Alps*, extending from the western side of Plato to about N. lat. 42° and W. long. 1°, mark out the north-western limits of the Mare Imbrium. They are intersected about midway by the great Alpine valley and include many other objects of interest. Their loftiest peak, Mt. Blanc, attains an altitude of at least 12,000 feet.

(b.) *The Caucasus* form a vast mountain barrier between the Palus Nebularum, in the north-west corner of the Mare Imbrium, and the north-east side of the Mare Serenitatis. They include the fine object Calippus, on the east of which is a peak 19,000 feet in height. A magnificent view of sunrise on this region is obtained when Cassini is on the morning terminator.

(c.) *The Apennines*, the grandest range on the visible surface, extend in a bold curve from Mt. Hadley in about N. lat. 27°, W. long. 5° 30′ to Mt. Wolf, west of Eratosthenes. Their lofty escarpment forms the south-west border of the Mare Imbrium. They attain their maximum height (20,000 feet) between Mt. Bradley and Mt. Huygens, and rarely fall lower in this neighbourhood than 10,000 feet above the Mare. Their details will repay careful study at all times, especially as regards the valleys, craters (of which Conon and Aratus are brilliant examples), and peaks which they include. As Neison points out, they are in many respects analogous to the high plateaux and ranges of Central Asia, and they also resemble many terrestrial chains in presenting a steep face to the sea, and a much more gentle gradient in the opposite direction. They are observed to the best advantage near lunar sunset when the intricate structure of their south-western slopes can be

satisfactorily scrutinised. As referred to under the head of clefts, a range of lower heights running parallel to the main chain is found on the Mare about ten or twelve miles distant. These mountains should be examined under evening illumination, as at sunrise they are involved in the shadows of their loftier neighbours.

(d.) *The Carpathians.*—A less lofty and different type of heights from the foregoing, consisting of great mountain masses either isolated or grouped together, without displaying the steep escarpment on one side and the gentle declivity on the other. The small ring-plain, Gay-Lussac, may be regarded as the centre round which they are arranged. Mayer stands at their extreme eastern end, near which formation is the loftiest peak (7,000 feet). They form the southern border to the Mare Imbrium.

The Sinus Iridum Highlands.—A magnificent, broad, and intricate mountain system bordering the beautiful Sinus Iridum from Prom. Heraclides to Prom. Laplace, including peaks upwards of 12,000 feet in height, many complicated valleys, and some noteworthy ring-plains.

The Alps, the Caucasus, the Apennines, and the Carpathians form a well-defined and almost unbroken curved border to the Mare Imbrium from Plato to Mayer, giving it, if viewed when the moon is a day or so past the first quarter, the appearance of a vast walled plain.

(h.) *The Hæmus* present a lofty escarpment to the Mare Serenitatis, which they border on the south and south-east, from near Pliny to the Apennines east of Sulpicius Gallus; the lofty Prom. Acherusia, forming their westerly termination, and the brilliant ring-plain Menelaus are the most prominent features associated with them. The highest peak, near Taquet, is nearly 9,000 feet in altitude.

(k.) *The Pyrenees* extend from the east side of Guttemberg along the west border of the Mare Nectaris to the district west of Bohnenberger. The loftiest point (nearly 12,000 feet) occurs south-east of Guttemberg.

(m.) *The Altai.*—A long conspicuous serpentine range extending from the south-east side of Piccolomini, passing slightly north of Pons and terminating between Tacitus and Catherina. These mountains are best seen under evening illumination.

(n.) *The Riphæan Mountains.*—A remarkable range of moderate altitude running in a meridional direction south of Landsberg. Towards the centre they expand into a considerable mountain mass, and as they proceed northwards divide into two distinct branches.

(s.) *The Taurus.*—The wild mountainous region extending from the west side of the Mare Serenitatis near Le Monnier and Littrow in a north-westerly direction towards Geminus and Berzelius is thus designated. It includes a number of interesting objects, but from its position its details are less suited for observation than those of many other mountain systems.

The Teneriffe Range.—A comparatively low range of bright mountains in the Mare Imbrium, south-east of Plato. Schroeter estimated the height of one peak to be 8,000 feet.

The Straight Range.—These mountains, situated to the east of the last, are nearly parallel to the northern shore line of the Mare Imbrium between Plato and Laplace.

The Percy Mountains.—The lofty highlands so termed lie between Gassendi and Mersenius, forming the border to the Mare Humorum in this region.

The Harbinger Mountains.—A so-called mountain-system, consisting of isolated elevations, north-west of

Aristarchus. The most prominent portion of it is, however, evidently an incomplete (partially destroyed) ring-plain. If it is examined about the time when the east wall of Aristarchus is on the morning terminator it presents an appearance which clearly displays its true character.

The Hercynian Mountains.—A fine range near the limb, east of Briggs and Seleucus.

D'Alembert Mountains.—On the east limb, extending from S. lat. 19° to N. lat. 12°.

The Cordilleras.—Near the east limb, extending from S. lat. 23° to S. lat. 8°.

The Rook Mountains.—On the east limb, extending from S. lat. 39° to S. lat. 16°. Some of the peaks attain an altitude, according to Schroeter, of 25,000 feet.

The Doerfel Mountains.—On the south-east limb, extending from S. lat. 80° to S. lat. 57°. They include many peaks exceeding 15,000 feet in height.

The Leibnitz Mountains extend from S. lat. 70° on the W. limb to S. lat. 80° on the east limb, and contain some giant peaks, which in four instances, according to Schroeter and Mädler, attain an altitude of at least 26,000 feet.

[Other ranges noted by Neison, *Selenographical Journal*, vol. iii. p. 52.]

M. Mountains (W. limb), N. lat. 32° to N. lat. 14°.

N. Mountains (W. limb), N. lat. 8° to S. lat 8°.

S. Mountains (W. limb), S. lat. 12° to S. lat. 31°.

T. Mountains (W. limb), S. lat. 39° to S. lat. 54°.

Q. Mountains (E. limb), N. lat. 32° to N. lat. 43°.

P. Mountains (E. limb), N. lat. 54° to N. lat. 66°.

Humboldt Mountains (W. limb), N. lat. 72° to N. lat. 53°.

North Polar Ranges, from N. lat. 81° (E. long.) to N. lat. 74° (W. long.).

There is a wide field for observers, as yet in great measure unexplored, in carefully delineating the outlines and recording the position of the principal peaks of the great mountain ranges which lie in the neighbourhood of the lunar limb. It is a branch of selenography which has hitherto been followed in a very unsatisfactory and desultory manner, and might well form a subject of special study. These ranges are, of course, alternately brought into prominence and withdrawn from view by libration, and it is only by carefully observing their localities under all possible conditions that an accurate knowledge of their details can be obtained. The position angles of the principal peaks of each range should be taken, or, if this method is not available, their place determined by means of alignments with known objects.

Isolated Mountains.—There are many objects more or less conspicuous which may be placed under this head. The following list includes some of the most noteworthy:—

Pico.—A bright steep mountain, rising abruptly from the Mare Imbrium, south of Plato, to a height of about 8,000 feet. There is another small bright triple-peaked mountain a few miles south of it.

Piton.—A bright mountain, some 7,000 feet high, in the Mare Imbrium, about midway between Piazzi Smyth and Cassini.

Fontinelle A.—An isolated mountain about 3,000 feet high, in the Mare Frigoris, south of Fontinelle.

Le Monnier A.—A peak of about 3,000 feet in altitude, which probably once formed part of the wanting eastern border of Le Monnier.

Archimedes Z.—A small mountain group a few miles east of Archimedes.

Mt. Argæus.—A bright mountain mass towering 8,000 feet above the Mare Serenitatis, north-west of Dawes. A fine object when Plinius is on the morning terminator.

Eratosthenes I *and* X.—Two adjoining mountain groups north of Eratosthenes, the first consisting of four or five elevations well worth observing under a low sun, and the last resembling, under like conditions, a small square enclosure with moderately lofty walls on the south and east, the included space being much darker in tone than the surrounding Mare.

The Stag's Horn Mountains.—A conspicuous mountain mass at the southern end of the straight wall, about 2,000 feet above the surface at its base.

Caroline Herschel.—A few miles east of this formation is a bright mountain with two peaks about 1,200 feet in height.

Gruithuisen b.—A little east of this bright craterlet is a fine mountain rising 6,000 feet above the Mare.

Mairan.—Some distance east of this object is a group of three bright little mountains, the largest being 800 feet above the Mare.

Fra Mauro.—There is a fine mountain, 2,300 feet high, east of this formation.

Gambart ε *and* Z.—About midway between Gambart and Stadius. ε, remarkable, according to Neison, for retaining its brightness at full (7°) when near the terminator.

Secchi.—Immediately south of this formation stands a conspicuous and lofty mountain.

Manilius A *and* β.—The former, north-west of Manilius, is 5,500 feet, and the latter, some distance on the east, 2,000 feet in altitude.

Autolycus A.—A lofty peak south of Autolycus.

Cassini ε and δ.—Two magnificent mountain masses north of Cassini, the first 5,000 feet and the second 6,000 feet high.

Mt. Hadley β.—A mountain 8,000 feet high, north of this promontory.

Euler β.—A bright mountain 3,600 feet high, south-west of Euler.

CENTRAL MOUNTAINS.—These objects, so generally found occupying a central position on the floor of ring-plains and craters, either in the form of vast and complicated masses many thousands of feet in height and covering areas of 100 square miles or more, as in Gassendi, Copernicus, Theophilus, Petavius, and many others; or as solitary peaks, differing widely in importance and visibility, should be observed under all conditions of illumination and careful sketches drawn of their details, and a search made for craterlets on their flanks and summits. Special attention should be paid to the shape and extent of their shadows at various times, and of their brightness under different solar altitudes. Some of these features are excellent tests for definition, as for instance the central peaks of Thebit *l* and Bessarion. In certain formations, notably in Atlas and Hercules, there are rings of isolated mountains in the interior which may possibly represent the remains of partially destroyed craters. That in Hercules adjoins the bright crater D on the north, and can only be seen as a whole under favourable conditions.

BRIGHT RAY-SYSTEMS, LIGHT STREAKS, LIGHT-SURROUNDED OBJECTS, &c.—The, as yet, unexplained phenomenon of the bright rays or streaks which under a high Sun are seen to radiate in every direction from certain centres, and the remarkable environment of light surrounding like a nimbus or completely enveloping many

formations, are features to which observers should frequently devote their attention. The rays from Tycho, Copernicus, and Kepler are so obvious that at full moon they may easily be seen with an ordinary opera-glass, and in the majority of instances these rays are best observed with low powers. In the early and rude charts of Fontana, Cassini, Mayer, and others, they hold a prominent place, but they have never been systematically mapped on a large scale. Those emanating from Tycho are aptly said by the late Professor Phillips 'to radiate like false meridians, or like meridians true to an earlier pole of rotation.' Hundreds of distinct rays originate at this centre, some of which extend over the greater part of the Moon's visible superficies. They are especially numerous in the western hemisphere, and in one instance a ray can be traced from Tycho through Godin to Menelaus, and thence across the Mare Serenitatis to Thales near the north limb. This branch of selenographical research may to a great extent be advantageously pursued by observers however humble their optical means, and a real addition made to the scanty knowledge we possess relating to the details of these wonderful features. In conducting the investigation special attention should be given to the following points :—

1. The course of the rays with reference to formations near which or over which they pass.

2. Their apparent width at various places.

3. To ascertain whether they are affected by the formations which they traverse, either by being disturbed or modified in their course, or by becoming brighter, darker, or ceasing to be visible at certain points, and to specially search for traces of them on the floors of deep craters, &c.

4. To note instances where the brightness of the objects they cross is affected by them.

5. To discover, if possible, any indications of the level of the surface traversed by the rays being modified by them.

6. To note their brightness (according to scale) under different angles of illumination, and to record under what solar altitude they first become visible or cease to be so.

It would also be well if observers were to undertake to map and catalogue, as carefully as possible, some of the principal ray-systems. It is a work which, it is believed, has not hitherto been attempted.

The following is a list of the centres of the PRINCIPAL RAY-SYSTEMS: *Tycho*, *Copernicus*, *Kepler*, *Anaxagoras*, *Aristarchus*, *Olbers*, *Byrgius* A, *Zuchius*.

MINOR SYSTEMS: *Autolycus*, *Aristillus*, *Proclus*, *Timocharis*, *Furnerius* A, *Menelaus*.

In addition to these there are a number of generally brilliant craters, surrounded by a bright silvery lustre, usually extending for some distance. Among these objects are: *Euclides*, *Bessarion*, *Hortensius*, *Censorinus*, *Parry* A (south of Parry) *Dionysius*, *Alfraganus* (large crater west of Taylor), *Birt* α, *Lichtenberg*, *Taquet*, *Gambart* A, *Alpetragius* B, *Cyrillus* A.

In many quarters of the Moon's surface, especially on the dark grey tracts and on the floors of large formations, are found small craters and crater-cones, which are the centres of ill-defined white patches. There are also numbers of small nebulous white areas of doubtful nature widely distributed on the Maria and elsewhere whose position and characteristics should be observed and recorded.

Allusion has already been made to the *light streaks* frequently found in connection with minute craters, crater-cones, and spots in the interior of some formations. Most

of them are objects of great delicacy, and can only be faintly traced under the best atmospheric conditions, though after a little practice the observer will find that they seem to grow in distinctness. They are found in *Plato*, *Archimedes*, *Fracastorius*, *Capuanus*, on the Maria, and in many other situations. In the case of Archimedes, under a high sun but not at other times, two of the principal streaks can be traced over the west wall to some distance beyond, adding considerably to the brilliancy of the surface they traverse. The well-known double streak, resembling a comet's tail, extending eastwards from Messier in the Mare Fœcunditatis, together with the fainter streaks in its neighbourhood, are more obvious examples of the same class of objects, as are also the streaks near Rosse in the Mare Nectaris.

THE ESTIMATION OF LUNAR TINTS.—In recording the brightness of lunar objects it is necessary to employ a standard scale. That now used by selenographers is as follows:—

0° = Black . . .	5° = Pure light grey.
1° = Black grey . .	6° = Light whitish grey.
2° = Dark grey . .	7° = Greyish white.
3° = Medium grey . .	8° = Pure white.
4° = Yellowish grey .	9° = Glittering white.

10° = Dazzling white.

The subjoined list of lunar objects, from the *Selenographical Journal*, classed approximately according to this scale, will serve as a guide to observers using it:—

0° Black shadows.

1° Darkest portions of the floors of Grimaldi and Riccioli.

1½° Interiors of Boscovich, Billy, and Zupus.

2° Floors of Endymion, Le Monnier, Cæsar, Crüger, Fourier *a*.

2½° Interiors of Azout, Vitruvius, Pitatus, Hippalus, and Marius.

3° Interiors of Taruntius, Plinius, Theophilus, Parrot, Flamsteed, and Mercator.

3½° Floors of Hansen, Archimedes, Mersenius.

4° Interiors of Manilius, Ptolemäus, Guerike.

4½° Surface round Aristillus, Sinus Medii.

5° Walls of Arago, Landsberg, and Bullialdus. Surface round Kepler and Archimedes.

5½° Walls of Picard and Timocharis. Rays from Copernicus.

6° Walls of Macrobius, Kant, Bessel, Mösting, and Flamsteed.

6½° Walls of Langrenus, Theætetus, and Lahire.

7° Theon, Ariadæus, Bode B, Wichmann, Kepler.

7½ Ukert, Hortensius, Euclides.

8° Walls of Godin, Bode, and Copernicus.

8½° Wall of Proclus, Bode A, and Hipparchus C.

9° Censorinus, Dionysius, Mösting A, and Mersenius B and C.

9½° Interior of Aristarchus, Lapeyrouse Δ.

10° Central peak of Aristarchus.

For the general purposes of classification the above scale is convenient, but it is far too ambiguous to form the basis of observations made with a view to detect slight variations of tint. More or less uncertainty must always be attached to estimations of this character, even if it were possible to eliminate the purely physiological effects which tend to render eye-estimations erroneous. The employment of an apparatus similar to the Dawes' solar eyepiece (as suggested by Proctor), to cut off all extraneous light, and an invariable and absolute scale of tints, are among the most pressing needs of this department of selenography.

General Hints on Lunar Observation.—Most lunar objects are seen to the best advantage when near the terminator, or the ever-shifting line dividing the illumined from the unillumined portion of the disc. When thus placed, the Sun is either rising or setting in their

neighbourhood, and consequently details which would otherwise be invisible are brought into temporary prominence by their shadows, and trifling asperities or irregularities of the surface are thereby made manifest. Frequently, however, these shadows obscure other features which can only be seen when the Sun attains a greater altitude, while certain objects, always invisible with oblique illumination, become obvious under a high light. Hence the importance of observing a formation under every possible condition. Due regard must also be paid to the effects of libration, though, for objects near the centre of the visible disc, they may be generally neglected. It is useful to know, as pointed out by Birt ('British Association Reports, 1866–68'), that we see an object under nearly similar conditions every $59^d\ 1^h\ 28^m$, or, still more accurately, after the lapse of every fifteen lunations or $442^d\ 23^h$. The table at the end of this chapter, from the *Selenographical Journal*, will facilitate the finding the position of the terminator with sufficient accuracy to show what formations may be looked for on any given date, but its place with respect to two known objects on the Moon, one south of the equator and the other north of it, should be carefully recorded from actual observation on every occasion when a formation is sketched or described. With respect to the magnifying power desirable to use for lunar work, so much necessarily depends on the aperture of the telescope, the state of the air, and the character and position of the object to be examined, that no hard-and-fast rule can be laid down. On some nights (unfortunately few and far between in this climate) there seems to be scarcely any limit to the amplification that can be brought to bear on the Moon's surface, but as a rule, on an average night, powers of 200 to 250 on a 4-inch achromatic

and of 300 to 350 on a 8½-inch silver-on-glass reflector have been found most efficient. A little experience, however, will satisfactorily settle this point for each observer. Though it is, of course, not always practicable to observe the Moon when at its maximum, or meridian, altitude, an endeavour should be made to secure an observation when it is as far above the horizon as possible. No night, however unpromising, should be left untried. It often happens that much may be done even with a partially overcast sky, and occasionally a slight veil of cloud does not materially affect lunar details. Wind, as a rule, is fatal to definition, though one of the best observing nights in my recollection was partially cloudy, with a strong NE. gale blowing aloft, as evidenced by the rapidly drifting scud.

In interpreting what is revealed by the telescope, an endeavour must be made to realise the scale of the picture which is represented to us. Features that appear to be only little mounds or hillocks, are often in reality comparable to what we should describe on the earth as considerable hills, and even the minutest of the so-called craters or crater-cones are fully as large as the most prominent of the parasitic cones which abound on the flanks of Etna and other terrestrial volcanoes. We must remember that, the Moon, being in round numbers about 240,000 miles distant, a magnifying power of 400 (which is seldom exceeded in selenographical work in ordinary telescopes) brings us only to a distance of about 600 miles from the surface, a standpoint far too remote to allow us to obtain more than a general idea of its character, and which certainly affords no sure basis for dogmatising on its present condition. A good corrective of the judgment is to draw at the telescope one of the small formations of known dimensions with its surroundings, such as Kepler

or Marius, to map it to scale, and compare it with a representation of some terrestrial region, say Scrope's chart (reduced to the same scale) of the chain of Puys or extinct volcanoes west of Clermont, in Central France. This once volcanic region, occupying an area of about 20 miles from north to south and 15 miles from east to west, or 300 square miles, might easily find place within either of the above-mentioned ring-plains, and if transferred to Plato would scarcely cover a tenth of the interior.

Hints on Drawing Lunar Objects.—Many observers refrain from attempting to portray what they see in the telescope from a supposed lack of skill with the pencil, and supply its place with descriptive notes more or less elaborate. These, if accurate and easy of comprehension to others, are clearly of much greater value than a carelessly executed or indifferent drawing; but it is well-nigh impossible to choose terms that cannot be misinterpreted or to avoid expressions which, by reason of their vagueness, will not ultimately prove misleading and sources of endless doubts and misconceptions. More than one keen controversy in recent times on supposed instances of change in certain lunar objects showed what a cloud of uncertainty and mistrust frequently obscures written records unaccompanied by faithfully executed sketches. In work claiming to be of permanent value both methods should invariably go hand in hand. There should be no verbal description without an illustrative sketch, and no sketch without its accompanying catalogue. Every observer, however humble his optical means and however mistrustful of his artistic powers, should make it a rule to try to represent with the aid of pencil and paper what he sees. His efforts at first will perchance be crude and unsuccessful, though not absolutely valueless if he is careful only to draw what is easy

to represent and to note as accurately as he can the relative size, distance, and position of the various objects composing the picture. He will find, however, as he perseveres in the practice of sketching, that real progress will be made night by night, and before the lapse of many lunations he will have acquired sufficient skill to produce drawings of lunar features which will compare very favourably on the score of accuracy with many which are sometimes fondly imagined to fulfil all the requirements of selenography. Many observers make their sketches on far too small a scale and do not allow sufficient room for the distinct insertion of details. This necessitates frequent erasures and occasions subsequent uncertainty. In sketching a ring-plain, for instance, 30 or 40 miles in diameter and its surroundings, a scale of 15 to 20 miles to an inch will not be found any too large when we come to draw the irregularities of the walls, the intervening valleys, the craterlets, depressions, and other features which can be detected on and about its slopes. Moreover, if we make the mistake of commencing a drawing on too small a scale we discover, long ere it is completed, that the dimensions of small objects have to be exaggerated in order to show them at all, a circumstance which not only affects the correctness of the objects themselves but falsifies their relative distances and leads to a final result which is anything but satisfactory. A sketch-book of smooth paper about 10 inches by 7 inches will be found convenient for general use, or preferably a 'sketching-block' of about the same size, as being less heavy to hold, and a 'H. B.' pencil of good quality. The principal feature in the region under observation, whether ring-plain, crater, or what not, being first lightly sketched as carefully as possible, will serve as a convenient standard or scale in estimating the distances and

dimensions of the smaller objects in the neighbourhood, the more prominent of which may then be inserted. A few points will thus be obtained which may be utilised in making a rough triangulation, or as alignments for fixing the position of other features. When the more conspicuous objects are satisfactorily set down in this manner, the details visible in connection with the central object and the form and extent of the shadows should be carefully represented. This, though often done in a conventional and perfunctory way, is of great importance. The shadows should, when practicable, be estimated in terms of the apparent diameter of the formations to which they pertain, and a note made of the time of observation. When the broader features of the district have thus been drawn, a search should be made for minute craters, rills, and other delicate objects, the points already fixed rendering it an easy matter to insert them with accuracy. Before leaving the telescope the region should be finally examined with a view to detect omissions or mistakes. It may be questioned whether it is desirable to attempt to represent the varieties of shade which are displayed. As a rule it is perhaps better to rest satisfied with a tolerably correct sketch without any shading except the definite black shadows thrown by lofty objects, or in cases where well-marked differences of tone exist, as on the east of Dawes, the interior of Schickard, Alphonsus, and other formations, with a dotted line indicating their limits. If, however, the observer possesses the necessary skill, shading sufficient to show the inequalities of the surface and the general character of the ridges and other minor elevations adds materially to the value of his record. But he must guard against the temptation of sacrificing strict accuracy to pictorial effect, and must not insert a line or introduce a

tone which does not actually exist at the time of observation. Shading, if accurately and conscientiously done, is perhaps preferable to using conventional signs, arrows, &c., which frequently lead to uncertainty and error. An attempt to put on record in a sketch the tone of different parts of a lunar district, with a view to detect subsequent change, would be not only a very difficult, but, in the absence of a standard scale of reference, a very useless task, and should be avoided.

The sketch being now complete, each distinct object should be numbered, and a reference catalogue made in a special book, describing its appearance, position, and any other details relating to it which may be deemed necessary, together with notes referring to the time when the drawing was commenced and finished, the position of the terminator with respect to two known objects—one some distance to the north, the other some distance to the south of the equator—the magnifying powers used, and the state of the air.

However carefully a drawing is executed, it must not be supposed that the study of the region is complete after one night's observation. As the Sun rises higher in the lunar sky, and as its azimuth changes, features before obscured by shadows or imperfectly illuminated come to light, and a complete transformation scene gradually succeeds. Details regarded as doubtful when near the terminator now appear in their true character, while others which then seemed very striking and important have become insignificant and well-nigh invisible. The pencil must again get to work, and when the second drawing is complete the student will derive no small pleasure and instruction from the task of comparing it with the first, and in attempting to reconcile what are apparently inconsistencies in the two repre-

sentations, but which will probably ultimately turn out to be solely due to the different conditions that prevailed on the two nights. In short, the work must be continued till the region has been sketched many times, under both morning and evening illumination during the $59^{d.}$ period referred to above, before it can be said to have been thoroughly studied. It may then be compared with Mädler's, Neison's, or Schmidt's charts, and the points of disagreement noted for future investigation.

At the outset it will be well for beginners to confine their attempts at lunar delineation to the smaller and less complicated class of objects, leaving the large ring-plains and intricate features till they have acquired some degree of practice. Among the former, Euler, Bessel, Dawes, Pytheas, Lambert, Caroline Herschel, Torricelli, and Flamsteed may be suggested as being especially suitable. In any case no more should be attempted than can be carefully finished during one observation. Should clouds or bad definition prevent the completion of a sketch, it should be left unfinished, with a note to this effect, and on no account should any additions be made to it from memory. When the formation in question is again under observation an entirely fresh drawing should be made.[1]

FUTURE OF LUNAR WORK.—The foregoing remarks may possibly be considered as too exacting, and as

[1] A positive eyepiece, with two cross wires at right angles to each other in its focus, will often be found a very useful addition to a telescope employed in lunar work for noting alignments and for drawing purposes generally. To observers who wish to measure distances and determine positions, Neison's 'Differential Micrometer' will prove a most effective and inexpensive instrument, requiring no other adjunct than a fairly good ordinary clock, beating seconds. For a full description of it, and the methods to be employed in using it, see the *Selenographical Journal*, vols. i. ii. and iii.

making demands on time and patience which none but an enthusiastic observer would attempt to satisfy; but mere moon-gazing, without a definite object, though it may stimulate the curiosity and enlarge the ideas respecting 'other worlds,' sooner or later becomes a spiritless occupation, and ultimately gives place to some other equally transient amusement for leisure hours. Of late years selenography, as a branch of observational astronomy, has shown symptoms of decline, notwithstanding the notable multiplication of large telescopes which might do it good service but whose practical usefulness, so far as the Moon is concerned, seems, for some inscrutable reason, to be in an inverse ratio to their apertures. In our own country this waning interest in lunar work is perhaps more apparent than elsewhere, and seems to be due, in part at all events, to a widespread belief, founded on a purely gratuitous assumption, that the Moon is a dead world, or, as it is sometimes put, 'a burnt-out cinder of a planet,' and consequently that there is nothing to be learnt from observing it. Even were this dogma based on truth, the conclusion drawn from it would scarcely commend itself to those to whom the physical features of the planets are matters of interest, seeing that in the case of the Moon alone, among all celestial objects, we can study the actual surface-structure of another world unobscured by appreciable cloud or vapour; but, as a matter of fact, the question of visible change is as far from being settled as ever. Quite as much can be said in favour of it as against it, while many considerations of a physical nature certainly point to the probability of the present existence of volcanic activity on a sufficiently extensive scale to be detected in our telescopes. Hence the importance of a critical study of the Moon's surface on a definite plan. Desultory and

slovenly work is worse than useless. However excellent the telescope may be, unless there is an earnest and intelligent observer at the eyepiece, prepared to record faithfully and systematically what the instrument reveals, it can only be regarded in his hands as little more than a costly toy, serving no scientific purpose whatever.

Possessing Webb's 'Celestial Objects,' with its useful map, the beginner will at first be sufficiently provided as to books. As he progresses, however, he will need Neison's 'Moon,' and Beer and Mädler's and Schmidt's large charts, the latter being the most accurate and exhaustive representation of the Moon's physical features that has yet appeared.

APPENDIX I.

List of Lunar Formations shown in the Index Map.

(The numbers on the left correspond to those on the map; those on the right to the diameter of the formation, in miles, when known.)

North-west Quadrant.

	Miles		Miles
1. Rhæticus	—	13. Maskelyne	18
2. Godin	23	14. Taruntius	44
3. Agrippa	27	15. Apollonius	30
4. Sabine	18	16. Picard	21
5. Ritter	18	17. Cauchy	—
6. Manners	11	18. Proclus	18
7. Arago	18	19. Macrobius	42
8. Julius Cæsar	—	20. Maraldi	—
9. Boscovich	—	21. Vitruvius	19
10. Triesnecker	14	22. Jansen	—
11. Hyginus	4	23. Dawes	14
12. Ukert	14	24. Plinius	32

	Miles		Miles
25. Manilius	25	40. Burg	28
26. Menelaus	—	41. Aristoteles	50
27. Sulpicius Gallus	—	42. Eudoxus	—
28. Bessel	14	43. Alexander	—
29. Linnè	—	44. Callippus	17
30. Cleomedes	78	45. Theætetus	—
31. Römer	24	46. Cassini	36
32. Littrow	—	47. Autolycus	23
33. Le Monnier	33	48. Aristillus	34
34. Posidonius	62	49. Egede	—
35. Geminus	54	50. Great Alpine Valley	—
36. Messala	69	51. W. C. Bond	—
37. Berzelius	—	52. Archytas	21
38. Atlas	55	53. Gärtner	—
39. Hercules	46	54. Endymion	78

North-east Quadrant.

1. Sömmering	—	21. Cardanus	—
2. Schroeter	—	22. Kraft	—
3. Gambart	16	23. Seleucus	32
4. Reinhold	31	24. Briggs	33
5. Encke	20	25. Aristarchus	28
6. Kepler	22	26. Herodotus	23
7. Hortensius	—	27. Euler	19
8. Copernicus	56	28. Lambert	18
9. Stadius	43	29. Pytheas	12
10. Pallas	—	30. Timocharis	23
11. Bode	9	31. Archimedes	50
12. Marco Polo	—	32. Carlin	4
13. Eratosthenes	37	33. Caroline Herschel	—
14. Gay-Lussac	15	34. Delisle	16
15. Lohrmann	28	35. Diophantus	12
16. Hevel	71	36. Wollaston B.	—
17. Cavalerius	41	37. Wollaston	—
18. Reiner	21	38. Lichtenberg	—
19. Marius	27	39. Leverrier	—
20. Bessarion	—	40. Helicon	13

	Miles		Miles
41. Mairan	25	47. Harpalus	—
42. Sharp	24	48. Philolaus	45
43. Maupertuis	—	49. Birmingham	—
44. Plato	60	50. Piazzi Smyth	—
45. Fontinelle	23	51. Condamine	23
46. Horrebow	14	52. Bouguer	—

South-east Quadrant.

1. Ptolemäus	115	31. Bonpland	—
2. Alphonsus	83	32. Fra Mauro	—
3. Arzachel	65	33. Schiller	112
4. Alpetragius	27	34. Phocylides	—
5. Lassell	—	35. Wargentin	54
6. Thebit	32	36. Schickard	134
7. Straight Wall	—	37. Hainzel	55
8. Purbach	—	38. Cichus	—
9. Regiomontanus	65	39. Capuanus	—
10. Walter	100	40. Ramsden	12
11. Hell	18	41. Vitello	—
12. Maginus	—	42. Lee	—
13. Clavius	142	43. Doppelmayer	—
15. Wilhelm I.	46	44. Mersenius	41
16. Heinsius	—	45. Gassendi	55
17. Wurzelbauer	—	46. Vieta	51
18. Pitatus	—	47. Cavendish	32
19. Hesiodus	—	48. Letronne	—
20. Gauricus	—	49. Billy	30
21. Birt	—	50. Hansteen	31
22. Nicollet	—	51. Sirsalis	—
23. Bullialdus	38	52. Grimaldi	148
24. Mercator	30	53. Flamsteed	9
25. Campanus	30	54. Landsberg	28
26. Hippalus	—	55. Riccioli	106
27. Agatharchides	—	56. Mösting	14
28. Lubiniezky	23	57. Lalande	13
29. Guerike	—	58. Tycho	54
30. Parry	—		

South-west Quadrant.

	Miles		Miles
1. Albategnius	65	31. Baco	—
2. Parrot	41	32. Vlacq	57
3. Argelander	—	33. Riccius	51
4. Airy	—	34. Neander	34
5. Donati	—	35. Rheita	—
6. Werner	45	36. Reichenbach	—
7. Aliacensis	53	37. Curtius	—
8. Hipparchus	97	38. Zach	46
9. Stöfler	—	39. Fermat	25
10. Maurolycus	—	40. Polybius	—
11. Gemma Frisius	—	41. Sacrobosco	—
12. Zagut	—	42. Delambre	32
13. Piccolomini	58	43. Torricelli	—
14. Fabricius	56	44. Censorinus	—
15. Furnerius	—	45. Webb	14
16. Petavius	—	46. Santbech	46
17. Langrenus	—	47. Cook	—
18. Fracastorius	—	48. Beaumont	—
19. Theophilus	64	49. Mädler	—
20. Cyrillus	—	50. Kant	23
21. Catharina	—	51. Descartes	—
22. Tacitus	28	52. Dollond	—
23. Almanon	36	53. Taylor	—
24. Abulfeda	39	54. Alfraganus	9
25. Goclenius	—	55. Apianus	39
26. Capella	—	56. Playfair	28
27. Isidorus	—	57. Poisson	—
28. Hypatia	—	58. Pontanus	—
29. Messier	9	59. Guttemburg	—
30. Pitiscus	52		

APPENDIX II.

Position of the Lunar Terminator.

TABLE I.

Position of the Terminator of the Moon on March 1st, Noon G.M.T. of each year.

	°	′		°	′		°	′
1780 . .	145	40	1810 . .	143	48	1840 . .	117	33
1781 . .	26	2	1811 . .	14	10	1841 . .	347	55
1782 . .	246	24	1812 . .	232	13	1842 . .	118	17
1783 . .	116	46	1813 . .	102	34	1843 . .	88	40
1784 . .	334	59	1814 . .	332	58	1844 . .	306	52
1785 . .	205	20	1815 . .	203	20	1845 . .	177	15
1786 . .	75	42	1816 . .	61	41	1846 . .	47	36
1787 . .	305	4	1817 . .	292	3	1847 . .	277	58
1788 . .	164	16	1818 . .	162	26	1848 . .	136	11
1789 . .	34	39	1819 . .	32	48	1849 . .	6	33
1790 . .	265	1	1820 . .	250	49	1850 . .	236	55
1791 . .	135	23	1821 . .	121	11	1851 . .	107	17
1792 . .	353	36	1822 . .	351	33	1852 . .	325	29
1793 . .	223	58	1823 . .	221	55	1853 . .	195	52
1794 . .	94	21	1824 . .	80	17	1854 . .	66	14
1795 . .	324	43	1825 . .	310	40	1855 . .	296	37
1796 . .	182	55	1826 . .	181	2	1856 . .	154	48
1797 . .	53	17	1827 . .	51	25	1857 . .	25	11
1798 . .	283	40	1828 . .	269	26	1858 . .	255	33
1799 . .	154	2	1829 . .	139	49	1859 . .	125	54
1800 . .	24	25	1830 . .	10	11	1860 . .	344	7
1801 . .	254	46	1831 . .	240	33	1861 . .	214	30
1802 . .	125	9	1832 . .	98	55	1862 . .	84	52
1803 . .	355	31	1833 . .	329	17	1863 . .	315	15
1804 . .	213	35	1834 . .	199	39	1864 . .	173	26
1805 . .	83	57	1835 . .	70	1	1865 . .	43	49
1806 . .	314	19	1836 . .	288	13	1866 . .	274	11
1807 . .	184	41	1837 . .	158	36	1867 . .	144	33
1808 . .	43	3	1838 . .	28	58	1868 . .	2	45
1809 . .	273	25	1839 . .	259	21	1869 . .	233	7

TABLE I.—*continued.*

	° ′		° ′		°
1870 . .	103 29	1880 . .	210 43	1890 . .	330 5
1871 . .	333 52	1881 . .	81 4	1891 . .	200 26
1872 . .	192 3	1882 . .	311 26	1892 . .	58 39
1873 . .	62 26	1883 . .	181 48	1893 . .	289 1
1874 . .	292 48	1884 . .	40 1	1894 . .	154 24
1875 . .	163 11	1885 . .	270 23	1895 . .	29 46
1876 . .	21 23	1886 . .	140 45	1896 . .	247 57
1877 . .	251 45	1887 . .	11 7	1897 . .	118 19
1878 . .	122 8	1888 . .	229 20	1898 . .	347 40
1879 . .	352 30	1889 . .	99 42	1899 . .	119 2

TABLE II.

Position of the Terminator of the Moon at Midnight G.M.T., for each day of the year.

	March	April	May	June	July	August
	° ′	° ′	° ′	° ′	° ′	° ′
1	6 5	23 44	29 42	48 18	54 57	73 50
2	18 16	35 55	41 55	60 32	67 10	86 3
3	30 26	48 7	54 7	72 45	79 23	98 16
4	42 37	60 19	66 19	84 58	91 38	110 29
5	54 47	72 30	78 32	97 12	103 51	122 42
6	66 58	84 42	90 44	109 24	116 5	134 55
7	79 9	96 53	102 57	121 38	128 18	147 8
8	91 19	109 5	115 10	133 50	140 31	159 21
9	103 30	121 16	127 22	146 4	152 45	171 34
10	115 40	133 28	139 35	158 18	164 58	183 48
11	127 51	145 39	151 47	170 31	177 12	196 0
12	140 3	157 51	163 59	182 44	189 24	208 13
13	152 13	170 4	176 13	194 58	201 38	220 26
14	164 24	182 15	188 26	207 11	213 52	232 39
15	176 34	194 27	200 38	219 24	226 4	244 51
16	188 46	206 39	212 51	231 38	238 18	257 4
17	200 57	218 50	225 4	243 51	250 31	269 17
18	213 7	231 4	237 17	256 5	262 45	281 29
19	225 18	243 15	249 30	268 17	274 57	293 44
20	237 29	255 28	261 42	280 30	287 11	305 56

	March	April	May	June	July	August
	° ′	° ′	° ′	° ′	° ′	° ′
21	249 40	267 39	273 56	292 44	299 24	318 9
22	261 51	279 52	286 8	304 59	311 37	330 21
23	274 3	292 4	298 21	317 10	320 51	342 34
24	286 13	304 16	310 34	329 24	336 4	354 46
25	298 25	316 28	322 47	341 38	348 17	6 59
26	310 36	328 41	335 1	353 51	0 30	19 12
27	322 47	340 53	347 13	6 5	12 44	24 1
28	334 58	353 6	359 26	18 18	24 57	43 37
29	347 10	5 17	11 39	30 30	37 10	55 49
30	359 21	17 30	23 52	42 44	49 23	68 2
31	11 33	—	36 6	—	61 36	80 15

	September	October	November	December	January	February
	° ′	° ′	° ′	° ′	° ′	° ′
1	92 28	98 28	116 9	121 10	138 5	155 0
2	104 40	110 39	128 18	133 20	150 15	167 10
3	116 53	122 51	140 29	145 30	162 25	179 20
4	129 5	135 2	152 39	157 39	174 34	191 29
5	141 17	147 14	164 50	169 49	186 43	203 40
6	153 30	159 25	177 0	181 58	198 52	215 49
7	165 42	171 36	189 10	194 8	211 2	227 59
8	177 55	183 48	201 21	206 18	223 12	240 8
9	190 6	195 59	213 31	218 27	235 21	252 19
10	202 19	208 10	225 42	230 37	247 31	264 29
11	214 31	220 21	237 51	242 46	259 39	276 38
12	226 43	232 33	250 2	254 56	271 49	288 49
13	238 55	244 43	262 11	267 6	283 58	300 58
14	251 7	256 55	274 22	279 15	296 8	313 9
15	263 20	269 7	286 33	291 25	308 17	325 19
16	275 31	281 17	298 42	303 34	320 27	337 29
17	287 44	293 28	310 53	315 44	332 37	349 38
18	299 55	305 39	323 2	327 53	344 46	1 49
19	312 7	317 50	335 12	340 2	356 56	13 59
20	324 19	330 1	347 22	352 11	9 5	26 10

	September	October	November	December	Jauuary	February
	° ′	° ′	° ′	° ′	° ′	° ′
21	336 31	342 12	359 32	4 21	21 15	38 21
22	348 43	354 22	11 41	16 31	33 24	50 30
23	0 54	6 33	23 52	28 40	45 34	62 41
24	13 7	18 44	36 1	40 50	57 43	74 51
25	25 18	30 55	48 11	52 59	69 53	87 1
26	37 30	43 6	60 22	65 9	82 3	99 12
27	49 41	55 16	72 31	77 18	94 12	111 23
28	61 53	67 27	84 41	89 27	106 22	123 33
29	74 4	79 37	96 50	101 36	118 31	(135 43)
30	86 16	91 48	109 0	113 46	130 41	—
31	—	103 59	—	125 56	142 51	—

To find the position of the lunar terminator on any day in a year between 1780 and 1900. From Table I. take out the angle opposite the year, supposing the year to begin on March 1, so that, for example, January and February 1829, are to be considered the last two months of 1828. From this quantity subtract the angle opposite the given day in Table II., adding 360°, if necessary, to avoid negative quantities. An angle between 0° and 360° will be obtained, which will come under one of these four cases:—

I. Between 0° and 90°.—The sum by which it exceeds 0° will be the West Longitude of the Morning Terminator.

II. Between 360° and 270°.—The sum by which it falls short of 360° will be the East Longitude of the Morning Terminator.

III. Between 270° and 180°.—The sum by which it exceeds 180° will be the West Longitude of the Evening Terminator.

IV. Between 180° and 90°.—The sum by which it falls short of 180° will be the East Longitude of the Evening Terminator.

Example 1.—Required the position of the terminator on August 6, 1875, midnight.

In Table I., opposite 1875, is the angle . 163° 11′
In Table II., opposite Aug. 6, is the angle 134° 55′
Subtracting = 28° 16′

which comes under Case I. Therefore, Morning Terminator is in 28° 16′ West Longitude.

Example 2.—Required the position of the terminator on January 23, 1872, midnight.

In Table I., opposite 1871 (it being January), is the angle	333° 52′
In Table II., opposite January 23, is the angle .	45° 34
Subtracting =	288° 18′

which comes under Case II. Therefore, Morning Terminator is in 71° 42′ East Longitude.

Example 3.—Required the position of the terminator on April 30, 1842, midnight.

In Table I., opposite 1842, is the angle . . .	118° 17′
In Table II., opposite April 30, is the angle . .	17° 30′
Subtracting =	100° 47′

which comes under Case IV. Therefore, Evening Terminator is in 79° 13′ East Longitude, or it is a day before new moon.

If it be required to find the position of the terminator for some time before or after midnight, it is only necessary to make a corresponding alteration in the angle opposite the day in Table II. Thus for April 30, 9 P.M., the quantity 17° 30′ opposite April 30 must be diminished by $\frac{3}{24}$ or $\frac{1}{8}$ of the difference (17° 30′ − 5° 17′ = 12° 13′) between the values for April 29 and April 30, or 1° 32′ nearly. It will be, therefore, 15° 58′ instead of 17° 30′. Without material error it may be supposed that the terminator moves towards the east at the rate of 30′·5 per hour, and its position computed by adding or subtracting this amount, multiplied by the number of hours it is past or previous to midnight.

APPENDIX III.

Lunar Elements.

(*Chiefly from Neison's* Moon).

Synodical revolution . . .	$29^d\ 12^h\ 44^m\ 2^s{\cdot}684$
Distance (mean)	60·27035 of earth's radii 238,840·25 miles
„ (maximum) . . .	252,972 miles
„ (minimum) . . .	221,614 miles
Diameter (mean)	31′ 8″·00 2163·06 miles
„ (maximum) . . .	33′ 33″·20
„ (minimum) . . .	29′ 23″·65
Maximum geocentric libration in longitude	7° 53′ 51″·0
Maximum geocentric libration in latitude	6° 50′ 45″·0
Maximum parallactic libration .	1° 1′ 35″·0
„ geocentric libration .	10° 25′ 22″·0
„ libration (total) . .	11° 25′ 30″
Surface of Moon never seen . .	·4100
Surface of Moon that is visible at one time or another . . .	·5900
Angle subtended by one degree of selenographical latitude and longitude at the centre of the Moon's disc, when at its mean distance . .	16″·565
Length in miles of the same .	18·871
Miles at the centre of the Moon's disc, subtending an angle of one second of arc . .	1·139
Surface.	0·074478 of the earth's
Volume.	0·02033 of the earth's
Density	0·60419 of the earth's 3·444, Water being unity

Action of gravity at the surface .	$\left\{ \begin{matrix} 0{\cdot}16489 \\ \frac{1}{6{\cdot}065} \end{matrix} \right\}$	of the earth's
Period of similar phase . .	$59^d\ 1^h\ 28^m =$	2 lunations
or still more accurately . .	$442^d\ 23^h\ 0^m =$	15 lunations.

APPENDIX IV.

List of Selenographical Works and Maps useful for Observers.

Beer and Mädler. Der Mond. 1st edit. Berlin, 1834. Map 37½ in. diam., in 4 sections, and special maps of Petavius, Hyginus, Triesnecker, &c.

Mädler's Smaller Map, 12½ in. diam. Berlin, 1837. This is an excellent map for beginners, showing much detail and including many of the easier rills. The name of each formation is given in the margin, with a reference number on the map.

Lohrmann's Mondcharte, edited by Dr. J. F. J. Schmidt. Map about 37½ in. diam., in 25 sections. Fifty pages of explanatory text. Leipzig, 1878.

Neison's Moon. London, 1876. Map 24 in. diam., in 22 sections, with index map 12 in. diam., and special maps of Gassendi, Maginus, and Theophilus; and drawings of Copernicus, Agrippa, Godin, and Plato. The most complete work on selenography in the English language.

Charte der Gebirge des Mondes, by Dr. J. F. J. Schmidt, with 4to introduction, 303 pp. Berlin, 1878. Map 6 Paris feet in diam., in 25 sections.

The Moon, by R. A. Proctor. London, 1873. With 3 lunar photographs by Rutherfurd, and many plates, charts, &c.

Celestial Objects for Common Telescopes, by Rev. T. W. Webb, M.A., F.R.A.S. 4th edit. London, 1881. Map 12 in. diam., includes all the principal lunar features. Invaluable for beginners.

The Moon, considered as a Planet, a World, and a Satellite, by Jas. Nasmyth, C.E., F.R.A.S., and Jas. Carpenter, F.R.A.S.

London, 1874. Has a good index map of the Moon, and is illustrated by a number of very effective photographs of various lunar regions taken from models.

Klein's Anleitung zur Durchmusterung des Himmels, contains a full account of the principal rills. Brunswick, 1880.

La Lune, by Amédée Guillemin. Paris, 1868.

Der Mond, by J. F. J. Schmidt. Leipzig, 1856.

Der Mond, by O. M. Opelt, with 2 maps in fol. Leipzig, 1879.

Milner's Gallery of Nature, contains a very useful map of the Moon, 7½ in. diam., showing a few rills.

Arago's Popular Astronomy, Smyth and Grant's translation, includes a good lunar map, 6¾ in. diam., and much information relating to the physical features of the Moon.

The Astronomical Register, No. 207, has an index map of the Moon by Birt, 4¾ in. diam.

British Association Reports, 1865, 1866, 1867, 1869, 1871, 1872, contain reports of the Lunar Committee, with outline maps of certain areas.

Vogel's Chemistry of Light and Photography (Int. Scientific Series) has an excellent photograph of the Moon, about 4½ in. diam., showing a great amount of detail very distinctly.

Handy Map of the Moon, by T. K. Mellor. London, 1887. This map is 11¼ in. diam., and is specially convenient for observatory use.

CHAPTER V.

THE PLANETS.

PAST AND FUTURE OF PLANETARY OBSERVATION.—We are indebted to the telescope for all the knowledge we possess regarding the appearances of the planets and their satellites, and of the phenomena attending their revolutions. Looking back through the years which have elapsed since Galileo first applied his crude little instrument to the examination of the heavenly bodies, we shall see what a vast array of details have accumulated. But it must be confessed that the results, though so extensive and interesting, are in a measure disappointing, and not nearly as complete as we might have expected. The planets are so prolific in features of interest coming readily under observation that we are surprised at the comparative inadequacy of our information and the many doubtful points still awaiting more complete investigation.

It is true the old observers had to struggle against difficulties of no common order. Their instruments were of enormous length, and about as difficult to manage and ineffective in performance as one can well understand. But this does not apply to modern conditions when the facility and capacity of our telescopes have been so greatly augmented. The number of thoroughly efficient instruments in public and private observatories and in the hands of amateurs is enormous, and yet we do not recognise any

corresponding increase in the amount of really valuable work. This must be due either to want of energy on the part of observers or to the actual exhaustion of discoverable objects. The latter cannot be the true explanation. Though the field has been well explored during preceding generations, there still remains a harvest of boundless extent. We must then conclude that the progress of discovery is in great measure impeded by other causes. We believe that in some cases there is a want of method, in others a lack of determination, and of course in many instances amateurs cannot spare the time for much habitual work. They can only accept opportunities now and then according to circumstances. Disconnected work of this kind is rarely valuable, for a man thus harassed by other imperative calls is not likely to labour with system or, indeed, with much enthusiasm, realising as he does the necessarily broken character of his labours. With those amateurs who have both the leisure and disposition to follow the science with a fair degree of continuity the case is different, and it is gratifying to notice that indication of increasing energy, which is the sure augury of success, is now being developed in a remarkable degree.

It is difficult to prescribe rules for the guidance of those whose work is influenced by many different circumstances and directed to widely different branches of astronomy. We may, however, note a few facts which commend themselves as likely to facilitate successful observation, and perhaps to encourage interest in astronomical work. Our remarks apply specially to the observation of planets, which is, indeed, one of the most promising and attractive branches held out to amateurs.

Instruments.—With regard to instruments, the observer need not be discouraged if his means are limited.

Reflectors of some 6 or 8 inches aperture are often in the market at a nominal price, and if the figure of the speculum is good and the mounting steady and serviceable he need have no apprehension as to any supposed great inferiority of capacity relatively to those possessing instruments of very large calibre. He may fully depend upon the competency of his modest appliances, at least as regards planetary work, and experience will soon convince him of the fact.

The cheapness of reflectors, the perfect ease with which they permit of lengthened observation, and their achromatism strongly recommend them to favour. Their liability to tarnish, is, however, an undoubted drawback, and aperture for aperture they give less light than refractors. When, however, the relative cost of the two forms of instrument is considered, a great advantage remains with the reflector, especially in the larger sizes, so that we are not surprised at the increasing demand for specula of late years. But it matters little whether the reflector or refractor be the character of instrument selected. The moot point as to their relative efficiency has been often discussed without any definite conclusions other than those arising chiefly through prejudice. Either construction, from the hands of a good maker, will be certain to prove eminently satisfactory. Amateurs with small apertures are apt to consider themselves practically unable to compete with the fine instruments now becoming so plentiful, but this is a misconception. It should be remembered that moderate sizes possess a great advantage as regards definition, and this is of the utmost consequence. No benefit accrues from an enormous command of light when the object observed is rolling and seething in undulating vapours! Delicate features on a bright planet become indistinguishable amid the glare and atmosphere tremors

inseparable from large apertures. In instruments of about 8 in. these evils are little recognised, and, when magnifying power is suitably blended with light, the object is seen not only with a perfectly hard and steady contour, but the faintest details come out now and then with that remarkable sharpness of expression which never fails to delight the eye of an experienced observer.

All possible care should be directed to the telescope and its perfect adjustment, for only able workmen can accomplish good work with indifferent tools. Every means must therefore be adopted to maintain the thorough efficiency of our instruments, so as to ensure their best performance. By proper and frequent attention to this matter we shall find that our own pleasure and the interests of astronomy go hand in hand. We must, however, remember that the telescope is not a toy to be admired, to be dismounted and dismembered, then reset, to be tested and retested, and to be used but rarely in practical observation, lest it should deteriorate by frequent exposure. It is an acknowledged fact that some people spend more time on their telescopes than on their observations.[1] This is deplorable. We

[1] I once heard of a man who had a powerful battery of nearly two score telescopes of different apertures, including every known construction, but it was only with something of an effort that he managed to secure about one observation in a month! How different to the character of Sir William Herschel, who tells us (*Phil. Trans.*, vol. lxxiii. p. 249) that he on 'many a night, in the course of eleven or twelve hours of observation, carefully and singly examined not less than 400 celestial objects, besides taking measures of angles and positions of some of them with proper micrometers, and sometimes viewing a particular star for half an hour together with all the various powers of his telescope.' Though he had no shelter but the sky above, he possessed within himself that indomitable spirit of perseverance, that innate aptitude and love for his subject, which enabled him to amass results of extraordinary extent and value.

should regard our instruments as simply the means to a certain end, and employ them on every legitimate occasion. Exposure may affect their appearance, though it can hardly render them unserviceable. The writer's 10-inch reflector has been standing in the open without any shelter whatever for fifteen years, and is comparatively uninjured. It will last his time.

But an observatory undoubtedly possesses advantages if care is taken to prevent air currents and to ensure stability. It affords shelter from inclement weather, and protects the telescope from annoying vibrations caused by wind, and generally facilitates work by enabling the observer to have his eyepieces, charts, accessories for drawing, &c., close at hand. Several plans for the economical erection and equipment of suitable observatories have been discussed at different times in the *English Mechanic*, and we leave the reader to make his own choice, for much depends upon the intended outlay, on the special line of observation proposed to be taken up, and on individual ideas as to the requirements in such cases.

System in Observations.—As to the plan and object of the observations, let us infer that the aim is to advance our knowledge as to the physical appearances and changes of the planets, and also, possibly, as to the motions and other phenomena of their satellites. The eye requires careful training in this work, and the best school is practice, which the observer will acquire as he goes along. In every case he should avoid the erratic employment of his means, but rather allot himself a definite range of objects for each night, and prepare himself by the aid of diagrams, tables, or any other desiderata, so that valuable time may not be lost by the necessity of making references during the actual progress of observations. An observer

will find by means of a working list that he will not only accomplish more, but that the pleasure felt in its performance will be keener because uninterrupted, and the issues more valuable because formed on method. Even negative observations will have importance, and should be always recorded. An object looked for and found invisible will perhaps be found to have a meaning more significant than a feature invariably seen, which can hardly fail to induce the monotony resulting from oft-repeated observation. All records of astronomical work should be as comprehensive as possible and written out immediately, for the memory is not sufficiently retentive to hold the facts and impressions which the observer accumulates during a prolonged examination of different objects.

Planetary Drawings.—With respect to drawings, it is almost needless to say that the main desire should be to reproduce with perfect fidelity of detail the image portrayed in the telescope. Very doubtful markings, such as the amateur may fancy his eye just barely reaches now and then, should not be included unless he regards the evidence of their existence such as to warrant him in giving them a place. Features of which we have nothing more than a strong suspicion are, however, best omitted and relegated to future scrutiny, unless their identity can be established with similar objects in the drawings of other observers. In any case, the inclusion of detail, as a means of enhancing the mere pictorial effect, cannot be too strongly deprecated. Observers should scrupulously endeavour to make their delineation a faithful record of fact. Some observers exhibit a decided tendency to be imaginative, and fail to discriminate between real and false impressions. Many curious discordances originate in this way, and occasion doubts not easily removed. The tele-

scope is sometimes in fault, and an abnormal state of the atmosphere will often induce peculiarities in the telescopic image. All questionable markings should therefore be discarded. Inaccurate or overdone drawings or descriptions usually bear self-evident anomalies leading to their condemnation. The zealous searcher after truth for its own sake will be content to reproduce objects simply as they are displayed to him, without any embellishments, for we may depend upon it we cannot improve Nature by any artifice of the imagination or a too lavish use of the pencil.

General Hints.—Many observations have become obsolete by their isolated or broken character. It is of the greatest importance that whenever a feature of unusual interest, such as a new marking on a planet, is observed, it should be closely followed for months if possible, aye, and for years if need be. To say that we have seen a certain thing at a certain time is of little significance. Something more than the mere record is wanted. What Science will ask her votaries is, 'What is the object? What is its position at the present time? What velocity regulates its apparition? What changes affect it? What are its dimensions?' It is necessary in the interests of astronomy that such questions should be answered in part at least, and observers should make it their business to seek out these things with more critical amplitude. Our telescopes are competent enough. Shall we confess the fault lies with us, and that we regard such matters with a nonchalance amounting to indifference? We trust that the increasing diligence of amateurs evinced at the present time proves them to have become fully alive to the salient requirements of observation.

Amateurs should not be easily discouraged by con-

spicuous failure at the outset, or by obstacles which they had not foreseen. A night seemingly very lucid and free from vapour is often very disappointing. A little haze, or thin cirrus cloud, sufficient to perceptibly dim the stars, as seen by the naked eye, often betokens very sharp definition, and it is only at such times that objects are presented under their most favourable aspect. But a night of bad definition should not be too hastily condemned until work has been attempted several different times, for definition, though sometimes found execrable in the early evening, will show a marked improvement later on. These changes occasionally occur very suddenly, the telescopic images exhibiting great variations at short intervals. The best opportunities should be utilised to the utmost extent, for they occur none too often, and delays must be always avoided, for they frequently result in the total loss of valuable observations. In large towns, or their immediate suburbs, it should be remembered that the best hours for work will usually be very late at night or in the early morning. At other times the atmosphere is so charged with smoke and other heated vapours as to have a ruinous effect upon delicate observations.

A waste of time sometimes ensues from persistent attempts to discern well-known objects. Of course observers, especially those just entering the field, will be anxious to see for themselves some of the remarkable features displayed by the telescope in order to satisfy their curiosity and test the powers of their appliances. We cannot expect amateurs to put on harness immediately and enter upon systematic work before they have surveyed, with their own eyes, some of the wonders which have attracted them to take a practical interest in astronomy. Many persons simply acquire a telescope and a rudimentary

knowledge of the science as a means of spending a few hours of relaxation from the cares of business, and have no prospect of being able to enter with any thoroughness into the pursuit. With those, however, who encourage more extended views the case is different. They will soon experience something akin to monotony in the frequent examination of similar objects unless they have special ends in view. When a man takes up a certain department and follows it with consistent energy his interest increases as he advances step by step, and he finds himself not only in a position to add his quota to its development, but that the work has become more than ever a labour of love, and is leading him on through paths full of new and varied allurements.

In reporting observations it is always desirable to mention the aperture and power of the telescope employed. The power should be determined by careful observation, for it seems to be the invariable custom of opticians to deliberately overstate the power of eyepieces. It cannot be said that this is justifiable, though it has been the practice ever since the telescope came prominently into use. Its effect is to mislead observers, but they have a remedy in insisting upon the exact fulfilment of their orders, which it is a pity is not more often enforced.

THE PLANETS GENERALLY.—The progress of planetary discovery has been very rapid of late years owing to the large number of minor planets detected between the orbits of Mars and Jupiter. No fewer than 247 of these bodies are now known. There are eight major planets—viz. Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The six outermost of these are attended by subordinate planets or satellites numbering twenty in the aggregate, as far as known, and distributed as follows:—

Earth 1, Mars 2, Jupiter 4, Saturn 8, Uranus 4, Neptune 1. The number for the first four exhibit a series in duple progression, and we may fairly conclude no other satellites await discovery in these instances. But from analogy it is clearly to be inferred that Uranus and Neptune have each a numerous retinue of moons, the majority of which are, however, of such faint character (owing to vast distance) as to have hitherto defied the space-penetrating power of our largest telescopes.

The four exterior planets, Jupiter, Saturn, Uranus, and Neptune, greatly exceed the inner planets in regard to their actual dimensions. Jupiter is the largest of them all, while Saturn far exceeds any of the remaining planets. Mercury and Mars are very diminutive; the Earth and Venus are also relatively very small compared with the outer planets. But as regards their apparent brilliancy in the firmament much depends upon their distance from the Earth. Venus far outshines the other planetary members of our system. In 1861 G. P. Bond computed the lustre of Venus at maximum at 4·86 times that of Jupiter. She is often distinctly visible at noonday with the naked eye. Jupiter, though much inferior to Venus, is a brilliant object, and Mars also when he comes to opposition, as in 1877, in that region of his orbit nearest to the earth. Saturn, too, may be regarded as a conspicuous planet, though his great distance considerably moderates the effect. Mercury is much more brilliant than is commonly imagined, occasionally rivalling Jupiter, but his invariable immersion in the vapours and twilight on the horizon renders the planet seldom visible. Uranus may be distinctly seen with a good eye, but Neptune lies far beyond the scope of unassisted vision. Vesta and one or two others of the minor planets are within reach of the eye at favourable oppositions, but

Table of the Distances, Periods, &c., of the eight major Planets, and of the Moon.

Symbol	Name of planet	Mean distance from Sun	Relative distance from ☉ ⊕ = 1	Sidereal period	Real diameter	Apparent diameter			Inclination of orbit	Rotation period
						Max.	Min.	ean		
		miles		days	miles	″	″	″	° ′ ″	h. m. s.
☿	Mercury.	35,340,000	0·387	87·97	2,990	12· 9	4· 5	8· 7	7 0 8	25 — —?
♀	Venus .	67,270,000	0·723	224·70	7,660	66· 5	9· 7	38· 1	3 23 35	23 21 23?
⊕	Earth .	93,000,000	1·000	365·26	7,926	—	—	—	—	23 56 4
♂	Mars . .	141,730,000	1·524	686·88	4,200	30· 4	4· 1	17· 3	1 51 2	24 37 23
♃	Jupiter .	483,880,000	5·203	4332·59	86,000	50· 7	30· 8	40· 7	1 18 41	9 55 37
♄	Saturn .	887,130,000	9·539	10759·24	72,000	20· 3	14· 6	17. 5	2 29 40	10 14 24
♅	Uranus .	1,784,020,000	19·183	30688·39	33,000	4· 3	3· 5	3· 9	0 46 21	— — —?
♆	Neptune	2,795,060,000	30·054	60181·11	37,000	2· 9	2· 6	2· 8	1 47 0	— — —?
☽	Moon .	From Earth 237,300	—	27·32	2,160	33·31	29·21	31·26	5 8 40	27 7 43

such objects, owing to their minute character and the lack of detail under telescopic power, attract few observers to the scrutiny of their surfaces.

The rotations of the planets are performed in a direction from west to east (which is also the direction of their orbital motions and of the motions of their satellites except in the case of Uranus), and their periods vary according to size. Thus it is found that Jupiter rotates quickest of all, the periods deduced from observations of a red spot during the years 1878–83 being $9^h\ 55^m\ 37^s$, whereas Mercury probably occupies about 25 hours. The periods of Uranus and Neptune have not yet been determined, and a large degree of uncertainty is also attached to the periods assigned to the inferior planets Mercury and Venus. A certain law of rotation, not yet exactly revealed, appears to prevail amongst the planets. As to Jupiter and Saturn, the definite markings from which the times have been deduced are undoubtedly of atmospheric origin, and exhibit marked discordances, so that the exact rotation periods of the real spheres of these are still in a great measure involved in doubt.

As telescopic objects, Jupiter, Saturn, and Mars are far more interesting than the others, in consequence of the extent of detail perceptible on their surfaces. Venus, though displaying very faint cloudy patches and occasionally bright spots, and passing through a sequence of phases, is also very attractive, but her excessive lustre is a barrier to sharp definition. Mercury is seldom to be observed under good conditions, hence little has been certainly established with regard to his physical appearance. As to Uranus and Neptune, their immense distance enables them to evade any scrutiny of detail, but in respect to the former recent observations have conclusively shown that dark

parallel belts similar to those of Jupiter and Saturn form the leading features of his surface.

SUSPECTED PLANETS.—In addition to the planets already specified, others have been suspected, either from observations or from theoretical considerations. The probable existence of an intra-mercurial planet (provisionally called Vulcan) received a good deal of credence a few years ago owing to certain planetary bodies which, it had been alleged, were observed crossing the Sun. Le Verrier had also concluded that certain irregularities in the orbital motion of Mercury could only be satisfactorily referred to the disturbing action of some unknown planet, and hence the subject incited a good deal of discussion. A planet so near the Sun would, probably, frequently transit the disc, and a number of cases in which circular, opaque, and rapidly-moving spots have been observed projected on the Sun are brought forward in support of the affirmative view of the case. It must be confessed, however, that some of the most weighty of these have, on being submitted to rigorous tests, proved of very questionable value, and the balance of evidence decidedly favours the non-existence of the alleged new planet. Every year that passes renders the negative aspect of the question still more significant. Even the supposed view of the planet obtained by Watson and Swift during the total solar eclipse of July 1878 has led to nothing definite. It is inferred that such a body, if existing, would transit the sun in the early spring and autumn.

A new planet may perhaps with more reason be assumed to exist in a position exterior to Neptune. An attempt has been made to determine the approximate place of this body from the probable connection of its orbit with the aphelion distances of families of comets. It is well known

that Jupiter and the outer planets each have a group of comets whose wanderings from the Sun nearly coincide with the distances of their orbits. Two groups of comets are found beyond the position of Neptune, indicating the possible existence of two new planets with periods of about 1,000 and 5,000 respectively. Without going further into this speculative question we may remark that the nearest of these supposed planets, which is estimated at about the 13th magnitude, has already been looked for with the great Washington refractor, but such a research will require a most critical and patient investigation extending over a long period. The subject is interesting as showing the tendency of modern astronomy to seek yet farther afield for new bodies beyond the aims and instruments of former observers.

The problematical satellite of Venus, seen by several observers in the seventeenth and eighteenth centuries, may also be referred to here. Modern results have afforded little confirmation to the existence of such an object, though they have shown how easily a secondary spectral image of Venus, formed under circumstances chiefly of instrumental defect, may occasion a false impression. The false image has also been ascribed to atmospheric reflection or 'mirage.' This question as to the alleged satellite of Venus had, however, been almost forgotten until Houzeau recently opened it with a rediscussion of the observations. He adopts the hypothesis that the 'satellite' must really have been a planet exterior to Venus, and having a period of about 283 days. He names this theoretical planet 'Neith,' after the mysterious goddess of Saïs, whose veil no mortal raised, and infers that it revolves on the same plane as Venus, coming to conjunction with that planet every 2·96 years or 1,080 days. His deductions are rendered interest-

ing from the fact that on February 6, 1884, M. Stuyvaert, of the Brussels Observatory, saw a very brilliant point over the bright limb of the disc of Venus, and a few days later M. Niesten observed a small star lying just south of the planet, and showing a nucleus involved in faint nebulosity, which eluded his search on subsequent days. These observations are supposed to have been a reapparition of 'Neith;' but there is no evidence as to motion in the object observed, so that such a conclusion is open to very grave doubts. Indeed, we may fairly regard the whole theory untenable, though we would recommend observers not to lose sight of the question during their observations, or of the equally dubious one respecting Vulcan, for these matters are revived from time to time, and it is most important that all the evidence should be thoroughly sifted, so that they may ultimately receive settlement.

MERCURY.—Mercury has been seldom observed for physical peculiarities. The conditions of his elongations are such that he never recedes more than 29° from the Sun, though generally the distance is much less than this. He is, however, sometimes above the horizon for a period exceeding two hours, in the absence of the Sun. But, on account of his proximity to the horizon, it is hardly possible to obtain satisfactory telescopic views of the planet at such times. The best period is just after sunrise or before sunset, near the epoch of maximum elongation, when he is pretty free from the heated vapours which disturb the images of objects very low down. As a naked-eye object, the most suitable seasons are spring for morning observations and autumn for evening work, for the planet's declination is then N. of the Sun's place, and his position is nearly vertical over the point of sunrise or sunset.

One of the first efforts of the amateur will be to obtain

a naked-eye view of Mercury. He may be readily detected when the sky is very clear if the observer takes care to find the approximate position from an almanac and scans the region indicated with an opera-glass or small low-power telescope. The phase of the planet has a great influence on his apparent brightness. The best time to look for Mercury is either a few mornings after the W. elongations or a few evenings before the E. elongations, for a crescented phase may so enfeeble his light as to put him utterly beyond the reach of the naked eye, though other conditions may be very favourable.

It has been stated that some eminent observers have been baulked in obtaining a glimpse of this planet. The horizon is rarely clear when he happens to be presented to the best effect, and other circumstances, probably of local character, have originated failure in certain cases. A little patience and aptitude must, however, soon remove the chief difficulties. The planet shines with a strong sparkling light, giving evidence of a considerable degree of brilliancy could it be observed free from twilight and obscuring vapours. The contemplation of this evasive little 'messenger of the gods' is extremely fascinating, and exercises a most pleasing effect as its scintillations struggle through the haze and sun-glow ranging along the crest of the horizon.

As a telescopic object, the disc of Mercury is obviously less luminous than Venus. Some observers have noticed a rosy tinge about it, which the writer also noted in November 1882. Dark and bright markings of irregular form and probably variable character have occasionally been descried on the surface, and it is suggested by the most recent observations that they are somewhat analogous to those on Mars. The rotation period of about 24 hours,

commonly adopted on the original authority of Schröter, is questionable, but the exact period still remains doubtful. This planet, though so much neglected, offers a good prospect for future scrutiny—far more so, indeed, than Venus, whose markings are extremely delicate and difficult, notwithstanding her better position and larger diameter.

At intervals of thirteen years the elongations of Mercury recur under much the same condition and on nearly the same dates as before.

When he is passing through the immediate region of his orbit between the Earth and Sun, he is projected as a black circular spot travelling rapidly from E. to W. across the solar surface. Its form, no less than its velocity, distinguishes it from the ordinary Sun-spots. These transits are interesting, though comparatively rare. They invariably occur in the months of May or November, from the fact that the planet passes either the descending or ascending node (in other words crosses the ecliptic) in these months. The following is a list of all the transits of Mercury for the present century :—

1802	November 9	1861	November 12
1815	November 12	1868	November 5
1822	November 5	1878	May 6
1832	May 5	1881	November 7
1835	November 7	1891	May ♋
1845	May 8	1894	November 10
1848	November 9		

Thus the century includes thirteen of these phenomena.

The most important feature that we can suggest to future observers of this planet is that of the markings existing on the surface. Efforts should be made to recover them, so that something definite may be learned of their

character, and that the rotation period may admit of precise determination. Observations in the daytime will probably be most serviceable, and are, indeed, rendered imperative by the specially unfavourable conditions which obtain with the Sun below the horizon. There is an evident need of a close and systematic study of this planet, such as lies beyond the province of amateurs, and it has already been partially effected by Schiaparelli with the 8-inch refractor at the Royal Observatory at Milan.

VENUS.—Venus, though farther from the Sun, is more highly reflective than Mercury. Her resplendent, pure white lustre, though it attracts the admiration of the eye, is the cause of considerable glare and indistinctness when the planet is observed at night. Definition is usually best when the Sun is low on the horizon. The writer has often obtained exquisite views near sunset, and has been enabled to trace the perfect sharpness of the image, the gently undulating character of the terminator, and the faint grey appearances spreading over the surface, which have little claim to the term 'dark spots' by which they are usually known. These delicate forms are not so well visible in the daytime with a high Sun as on the approach of evening, and at night they are obliterated in the glare. It may be mentioned here that those who examine this, or any other planet, in the daytime must be careful to shield the telescope from the Sun's rays, or heated currents will be generated in the interior of the tube and the object will present the same utter disregard for the observer's wishes as on a thoroughly bad night, when the convulsions and inflations it undergoes are something astonishing in a large instrument, and must be seen to be believed.

Venus disappoints expectation in a telescope. This arises from several causes. There is an absence of any

very conspicuous markings. The faint, indeterminate, cloudy patches sometimes seen are of the most extreme tenuity. Bright spots are also visible now and then, especially at the extremities of the horns, when the planet is crescented. They have been noticed by so many different persons as to be placed in the region of well-established fact. But it is not known to what extent these or the faint dusty patches are permanent.

The apparent diameter of Venus will sometimes subtend a greater angle than that of any other planet, hence we should be enabled to perceive any variegated character of the surface, did it exist, with conspicuous effect. But the brilliancy of her disc is undoubtedly the result of a dense atmosphere illumined in very uniform degree by the Sun, which we must remember has far more strength on this planet than on the Earth. As to the existence of mountains on Venus, of such immense structure as to rear their summits above the dense atmosphere of the planet and become prominently visible at the vast distance separating us from the planet, we may well express ourselves with extreme reserve as to their reality. The evidence of those observers who have successively adopted the affirmative view as the legitimate issue of their observations possesses some weight, but they are not supported by later results. We can hardly avoid the suggestion that the appearances were deceptive, and that in any case extreme doubt hangs over them in the absence of further corroboration.

Observers who examine this beautiful planet should look for bright spots, either detached or connected with the cusps, and for the feeble shadowy markings involving the interior region of the surface. Irregularities at the terminator will also be very interesting; also the shading off

at this region, and the far greater brightness of the opposite limb.

The rotation period of Venus, though better substantiated than in the case of Mercury, still awaits a thoroughly reliable discussion. But the several values assigned by Cassini, Schröter, and Di Vico are in such fair agreement that, if we accept them as purely independent of each other, we must admit the axial motion of this planet is already found within small limits. Cassini gave $23^h\ 16^m$, Schröter $23^h\ 21^m\ 7{\cdot}98^s$, and Di Vico $23^h\ 21^m\ 23{\cdot}93^s$. We can hardly question the general accuracy of these results. Still the difficulties in following the markings with sufficient closeness, and the uncertainty as to their identity, lead us to hope for a more trustworthy solution of the problem.

As Venus revolves in an orbit interior to that of the Earth, it is evident that, like Mercury, she can never come to opposition to the Sun, like the superior planets, and be visible to us under the same highly advantageous circumstances. Her positions oscillate from one side of the Sun to the other, and we see her alternately as a morning and evening star. In the former position she was known to the ancients as Phosphorus or Lucifer, and in the latter as Hesperus. Her maximum apparent elongation extends to about 47°, and at times the planet remains above the horizon four and a half hours, in the absence of the Sun. Now and then she acquires remarkable brilliancy, and these special epochs are usually notified in our almanacs. It happens as she is traversing that region of her orbit some 40° from the Sun on the side farthest from the Earth when she is gibbous, and the telescope exhibits her disc under the same phase as the Moon three days before or after the 'full.' At these times Venus is easily detected with the

naked eye at noonday, and casts a very perceptible shadow at night, when the Moon is absent and the air pellucid. Indeed, the effect of her appearance is then such as to invite general remark and draw admiration from all beholders. When the twilight has withdrawn before her setting she diffuses a faint glow over the entire west, and directly transmits to us a flood of wavering brilliancy until, sinking below the horizon, she becomes the admired spectacle in other lands.

The apparitions of this planet are repeated in almost exactly the same manner and at the same dates as before at intervals of eight years (2,922 days), which very closely correspond with five synodical periods (2,920 days).

Transits of Venus are far more rare than those of Mercury. Between 1631 (the year of the first observed transit) and 2984 there are only 23 of these phenomena, so that on an average less than two take place in a century. They occur at intervals of 8, 121½, 8, 105½, 8, 121½, &c. years. The following is a short list of transits of Venus:—

1631	December 6	1874	December 9
1639	December 4	1882	December 6
1761	June 5	2004	June 8
1769	June 3	2012	June 6

The last transit of 1882 was well observed during its earlier stages in this country. These phenomena have a special importance as affording a method of determining the solar parallax which is now adopted as 8·78 (though still affected by a small range of unavoidable error), which corresponds to nearly 93 millions of miles for the Sun's mean distance from the Earth.

When Venus is near her inferior conjunction, and is reduced to a very narrow crescent, a faint degree of reflec-

tion from the dark side has been occasionally noticed. Not only is the sunlit bow of the planet seen, but the perfect outline of her periphery is traceable. An arc of feeble grey light connects the two extremities of the delicate crescent, and the interior region of the disc is seen perceptibly lighter than the dark background of the sky on which it is projected. This effect is somewhat similar to the ashy light which pervades the unillumined region of the Moon when about four or twenty-five days old and caused by earthshine. In the case of Venus, the twilight, seeming to involve her surface, is probably of atmospheric origin and the result of refraction.

Observers have in this planet an object which deserves most attentive study. Though her visible markings may be less definite than those of Mercury, her greater diameter and better position enable more frequent observation. As to the faint cloudy markings, they should be invariably looked for, and if sufficiently condensed to allow of definite measures of position, the micrometer should be used and their places fixed relatively to the E. or W. limb of the planet. If Venus is crescented at the time, then their distances from the cusps or the terminator should also be found, though it should be remembered that the terminator is not always theoretically true, and that one or other of the cusps, especially the south, is liable to show a very evident blunting. It will, therefore, be safest to refer the positions of spots to the limbs of the planet rather than to any part where defect or excess of phase can introduce a source of error.

When the planet occupies the superior part of the orbit, and is not far removed from solar conjunction, her phase is gibbous and the disc very strongly illuminated under the influence of the nearly vertical Sun. At such periods

observations of the markings will possess special value, as they may be noted in their central passages. But the apparent diameter of Venus is very small under such conditions, and it does not follow that a brighter surface will enable the dusky features to assume greater prominence. We should almost suppose that the increased illumination would have a tendency to obliterate them. The chief advantage is, however, that such markings, if visible, may be seen near the central region of the disc where the apparent motion reaches a maximum, and where, if they are re-observed and identified on several different occasions, a value for the rotation period might soon be deduced with tolerable exactness. In the case of multiple observations of spots just within the limb, the observations will be affected by a far greater range of error.

What has been mentioned relatively to the large dusky patches equally applies to the brilliant spots sometimes observed. Their position should be fixed with the utmost possible precision, and, when once detected, they must be followed with great persistency and the measures continued so that the extent of their displacement from night to night may be determined. Their forms and relative distinctness are also details of great significance which it is essential to note on every occasion. If this suggestion is carried out, we shall be enabled to reinvestigate many salient points regarding this planet, and to relieve them of the extreme doubt in which they have been involved for so many years. The time of rotation and inclination of the axis of Venus may not only be found from the materials thus obtained, but we shall be in a position to solve other questions respecting the physical condition of this planet. The degree of permanency exhibited by the spots, their peculiarities of form and the character of their variations,

may thus also be brought within the scope of reliable investigation.

The rotation period of Venus being little less than that of the Earth, the spots will occupy nearly coincident positions on the disc at the same hours on successive nights. The undulatory contour of the terminator will also for the same reason be likely to repeat itself in nearly similar form. But when the observations extend over many nights distinct changes will manifest themselves, and it is to the precise character and extent of these that the observer should direct his attention. It would be a matter for congratulation could the rotation period be computed from the motions both of the bright and dark markings, and also from the indentations in the terminator. Results obtained from such independent and various means would admit of very interesting comparisons, and even if not perfectly consistent with each other as regards the resulting times, they might still be individually reliable, for the Sun and Jupiter show considerable departures from a uniform period as derived from spots in different latitudes.

MARS.—Mars, though a small planet, is yet, from his comparative nearness to the earth and the bold outlines of his permanent markings, an object of somewhat special aspect. There is no other major planet which probably is so little enveloped and obscured in atmospheric vapours. The definite outlines of his surface markings become visible again and again with the same relative distinctness, and preserve a perfect integrity of figure so far as our knowledge extends. Hence the rotation period has been computed with exceptional precision, and we may rely upon it that this period is not that shown by atmospheric currents, but by objects which form the physical delimitations of his real surface. In this respect Mars appears to be

unique, for the other planets are all more or less involved in dense atmospheres, originating a series of variable phenomena visible in our telescopes; but their real surfaces are rarely if ever discerned, so that we are quite ignorant as to the material features underlying the outer vaporous envelopes.

But the mobile forms commonly recognised on the larger planets are totally different from the permanent lineaments of Mars, which have retained a uniformity enabling them to be accurately charted according to their positions in latitude and longitude. And systems of nomenclature have been variously adopted and applied to the principal markings. The method which seems to have found most favour is similar to that employed to designate the lunar formations. All the leading objects have received names selected from those of past or present astronomers, and thus a monopoly has been created which posterity may well feel inclined to sweep away. Of course, it is essential to approve some uniform means of facilitating reference, but we think the systems in vogue have led to extravagancies which will hardly survive future criticism. Names have been lavished upon certain features without sufficient discrimination, and which can lay feeble claim to such distinction. For the present, at least, let us be content to retain the names of a few principal spots, and leave the final adjustment to the discretion of those who in the years to come will be far better situated than ourselves to adopt a comprehensive style of nomenclature.

Very favourable oppositions of Mars recur at intervals of fifteen years. The last took place in September 1877, and in 1892 the circumstances will again be propitious. The opposition of 1877 will remain ever memorable for the discovery of two moons near the planet. These were

picked up by Professor Hall with the 26-inch Washington refractor, and the incidents of their detection form an enduring tribute to American diligence. How it was these satellites were allowed to evade the great Rosse reflectors year after year, or how they managed to entirely elude the vigilant eyes of Herschel and Lassell, whose telescopes were quite adequate to their discovery, and who were much engaged in this kind of work, is surprising enough when we consider that the satellites were well seen soon after the announcement of their discovery, with instruments of comparatively small aperture.

The physical appearances of this planet assume apparently variable forms as they are presented to the Earth under different angles during successive oppositions, owing to the inclination of Mars. Sometimes the N. hemisphere is most favourably presented, sometimes the S. At the region of the poles there are very bright white spots, so vivid that they seemingly obtrude beyond the true margin of the circular disc. These spots are said to be somewhat variable, and discrepancies have been recorded in other details, but the fact of absolute change requires further proof. With so many varieties in instruments, eyes, atmospheric conditions, and methods of delineation we have fruitful elements of discordance where few, if any, positive changes have actually occurred.

During the last few oppositions of Mars a number of very curious features, in the form of a complicated arrangement of dark lines having a general direction in latitude, though showing great deviation in some instances, have been described by Schiaparelli as visible especially in the years 1877 and 1879; and during the opposition of 1881–2 he not only appears to have recovered these objects, but went a step further and announced that they really

consisted of pairs of parallel lines in close juxtaposition. His drawings exhibit a perfectly marvellous structure of the surface, which contemporary observers here rather doubted, in view of the lack of confirmation from other sources. It is almost incredible how such features, plainly visible at a late period of a rather unfavourable opposition (January–February 1882), should have so long escaped detection. This in itself need not induce scepticism, however, seeing that, in many other cases, objects have avoided discovery long beyond the limits considered possible.

During future oppositions these singular duple lines will form a special aim of further researches. The points which suggest themselves are whether these features really exist on the planet's surface, and, if so, do they run over the disc in the remarkable profusion ascribed to them? Are they visible as very definite dark lines such as they are represented by their discoverer, or are they the extremely faint boundaries of areas of shading on the planet? The tendency of recent observation has certainly been to confirm their existence, but more extensive observations are required, not only in support of the results obtained by Schiaparelli, but in reference to probable variations amongst the curious forms which have given rise to so much controversy. A good telescope can hardly be more fittingly employed than in settlement of this question.

The rotation period of Mars is $24^{h.}\ 37^{m.}\ 22^{s.}{\cdot}626$, which corresponds to a daily rate of $350^{\circ}{\cdot}8922$. Spots observed in a certain position one night will, therefore, at the same time on the following night be seen about 9° E. The slow axial motion of Mars carries the markings through $14^{\circ}{\cdot}62$ in an hour, and at intervals of 40 days they are re-presented at nearly the same times as before, inasmuch as this interval corresponds with 39 rotations. To deduce

an exact rotation period, two observations, separated by a very long interval of years, are required. A comparison extending over, say, 15 years is too short for the purpose, for the rotation deduced, though possibly in error one-tenth of a second, will still accord with the positions of the spots to within nine minutes of time.

As to the satellites, we have already referred to the fact of their discovery. They are objects essentially needing a favourable opposition and a tolerably large telescope to ensure anything beyond mere glimpsing. At the opposition in 1892 a good 10-inch refractor or 12-inch reflector should reach them. Deimos is the nearest to Mars, being about 5,800 miles from his centre, and revolving in $7^h\ 36^m{\cdot}5$, which is equivalent to a daily rate of $1128^\circ{\cdot}8$. Phobos, the outer satellite, is distant 14,600 miles, with a period of $30^h\ 18^m{\cdot}0$ and daily rate of $285^\circ{\cdot}2$. These bodies are amongst the most minute in our system, the estimates of their real diameters varying between five and ten miles. As to their relative brightness, Professor Hall wrote in December 1877: 'Allowing for the glare of light around Mars, I think that at opposition we may assume that the outer satellite at its elongation was of the 12th magnitude. The inner satellite must be essentially brighter than the outer one, since I was able to observe it when less than 8″ distant from the limb of the planet, while I could not observe the outer satellite at a distance of less than 25″.' The outer satellite is, however, occasionally brighter than usual. On October 16, 1879, Professor Holden at Washington writes: 'Phobos easily seen; it is much brighter than I have ever seen Mimas at elongation, and I should say almost, if not quite, as bright as Enceladus is at elongation.'

These difficult objects are quite beyond the reach of ordinary amateurs, who will find the study of the planet's

markings more productive, and one little likely to decline in interest. Students will have an exhaustive base of reference in Dr. Terby's 'Areographie' in vol. xxxix. of the 'Memoirs of the Royal Academy of Sciences, Belgium, 1875;' Professor Schiaparelli's 'Topography of the Planet Mars,' Rome, 1878, and his further observations in 1881–2, published in the 'Memoirs of the Italian Spectroscopic Society,' vol. xi., 1882; also Mr. Green's 'Madeira Observations of Mars in 1877,' 'Memoirs of the R.A.S.,' vol. xliv.

THE PLANETOIDS.—The most notable facts in connection with these bodies are their great numbers, small size, and that they all revolve in orbits situated between Mars and Jupiter. Since 1845 the number discovered is something remarkable, and when much further multiplied by future additions, as there is every reason to expect, it will become a serious question how suitable names may be provided, and how to prevent complications respecting their identity.

M. Palisa, formerly at the Pola Observatory, but now at Vienna, has now (Sept. 1887) discovered no less than 60 planetoids; Professor Peters, of Clinton, U.S.A., 46; and the late Professor Watson, of Ann Arbor, U.S.A., found 22. The monthly aggregate of these discoveries shows the following proportions:—

January	13	July	14
February	22	August	28
March	22	September	45
April	33	October	27
May	21	November	26
June	13	December	5

Total = 269.

The difference between September and December is curious. Another remarkable feature connected with these

discoveries is that not a single one has been effected from the southern hemisphere.

Vesta is the largest of the group, being visible to the naked eye at opposition, and probably between 300 and 500 miles in diameter; but the great majority are much smaller, being below the 10th magnitude, and considerably less than 100 miles.

The planetoids can hardly be considered to afford much practical interest to amateurs, from the fact of their minute character, and the work of searching for them involves so much labour and systematic application that it justly falls on professional observers. The series of star charts recently issued by Professor Peters, and containing stars down to the 14th magnitude, will be extremely useful in the further development of these researches. The method usually pursued in seeking these bodies is to compare very faint stars seen in the telescope with those already charted (indeed several observers have constructed original charts for the purpose), and the comparisons and verification of positions occasionally lead to the detection of an object not included in the maps. Its place is then accurately fixed, and it is subsequently re-observed for traces of motion. If any displacement is found it must obviously be a planet, and in every case where the position does not conform with that of any known body, it is announced as a new discovery. Then observations are carefully obtained and the orbit computed when the resulting elements furnish another means of determining whether it has been seen before. The results of the computations are published in the 'Berlin Year-book,' where detailed information as to the movement of all the known minor planets will be found. On an average six planetoids have been discovered annually during the forty years since 1845. Annexed is a table of all those known up to September 1887.

Discoveries of Planetoids.

No.	Name of planet	Date of discovery	Discoverer
1	Ceres	1801, Jan. 1	Piazzi
2	Pallas	1802, Mar. 28	Olbers
3	Juno	1804, Sep. 1	Harding
4	Vesta	1807, Mar. 29	Olbers
5	Astræa	1845, Dec. 8	Hencke
6	Hebe	1847, July 1	Hencke
7	Iris	1847, Aug. 13	Hind
8	Flora	1847, Oct. 18	Hind
9	Metis	1848, Apr. 25	Graham
10	Hygiea	1849, Apr. 12	De Gasparis
11	Parthenope	1850, May 11	De Gasparis
12	Victoria	1850, Sep. 13	Hind
13	Egeria	1850, Nov. 2	De Gasparis
14	Irene	1851, May 19	Hind
15	Eunomia	1851, July 29	De Gasparis
16	Psyche	1852, Mar. 17	De Gasparis
17	Thetis	1852, Apr. 17	Luther
18	Melpomene	1852, June 24	Hind
19	Fortuna	1852, Aug. 22	Hind
20	Massilia	1852, Sep. 19	De Gasparis
21	Lutetia	1852, Nov. 15	Goldschmidt
22	Calliope	1852, Nov. 16	Hind
23	Thalia	1852, Dec. 15	Hind
24	Themis	1853, Apr. 5	De Gasparis
25	Phocæa	1853, Apr. 6	Chacornac
26	Proserpine	1853, May 5	Luther
27	Euterpe	1853, Nov. 8	Hind
28	Bellona	1854, Mar. 1	Luther
29	Amphitrite	1854, Mar. 1	Marth
30	Urania	1854, July 22	Hind
31	Euphrosyne	1854, Sep. 1	Ferguson
32	Pomona	1854, Oct. 26	Goldschmidt
33	Polyhymnia	1854, Oct. 28	Chacornac
34	Circe	1855, Apr. 6	Chacornac
35	Leucothea	1855, Apr. 19	Luther
36	Atalanta	1855, Oct. 5	Goldschmidt
37	Fides	1855, Oct. 5	Luther
38	Leda	1856, Jan. 12	Chacornac
39	Lætitia	1856, Feb. 8	Chacornac
40	Harmonia	1856, Mar. 31	Goldschmidt
41	Daphne	1856, May 22	Goldschmidt
42	Isis	1856, May 23	Pogson

No.	Name of planet	Date of discovery	Discoverer
43	Ariadne	1857, Apr. 15	Pogson
44	Nysa	1857, May 27	Goldschmidt
45	Eugenia	1857, June 28	Goldschmidt
46	Hestia	1857, Aug. 16	Pogson
47	Aglaia	1857, Sep. 15	Luther
48	Doris	1857, Sep. 19	Goldschmidt
49	Pales	1857, Sep. 19	Goldschmidt
50	Virginia	1857, Oct. 4	Ferguson
51	Nemausa	1858, Jan. 22	Laurent
52	Europa	1858, Feb. 6	Goldschmidt
53	Calypso	1858, Apr. 4	Luther
54	Alexandra	1858, Sep. 10	Goldschmidt
55	Pandora	1858, Sep. 10	Searle
56	Melete	1857, Sep. 9	Goldschmidt
57	Mnemosyne	1859, Sep. 22	Luther
58	Concordia	1860, Mar. 24	Luther
59	Olympia	1860, Sep. 12	Chacornac
60	Echo	1860, Sep. 15	Ferguson
61	Danaë	1860, Sep. 19	Goldschmidt
62	Erato	1860, Oct. 10	Förster
63	Ausonia	1861, Feb. 10	De Gasparis
64	Angelina	1861, Mar. 4	Tempel
65	Cybele	1861, Mar. 8	Tempel
66	Maia	1861, Apr. 9	Tuttle
67	Asia	1861, Apr. 17	Pogson
68	Leto	1861, Apr. 29	Luther
69	Hesperia	1861, Apr. 29	Schiaparelli
70	Panopæa	1861, May 5	Goldschmidt
71	Niobe	1861, Aug. 13	Luther
72	Feronia	1861, May 29	Peters
73	Clytie	1862, Apr. 7	Tuttle
74	Galatea	1862, Aug. 22	Tempel
75	Eurydice	1862, Sep. 22	Peters
76	Freia	1862, Oct. 21	D'Arrest
77	Frigga	1862, Nov. 12	Peters
78	Diana	1863, Mar. 15	Luther
79	Eurynome	1863, Sep. 14	Watson
80	Sappho	1864, May 3	Pogson
81	Terpsichore	1864, Sep. 30	Tempel
82	Alcmene	1864, Nov. 27	Luther
83	Beatrix	1865, Apr. 26	De Gasparis
84	Clio	1865, Aug. 25	Luther
85	Io	1865, Sep. 19	Peters
86	Semele	1866, Jan. 26	Teitjen

No.	Name of planet	Date of discovery	Discoverer
87	Sylvia	1866, May 16	Pogson
88	Thisbe	1866, June 15	Peters
89	Julia	1866, Aug. 6	Stephan
90	Antiope	1866, Oct. 1	Luther
91	Ægina	1866, Nov. 4	Stephan
92	Undina	1867, July 7	Peters
93	Minerva	1867, Aug. 24	Watson
94	Aurora	1867, Sep. 26	Watson
95	Arethusa	1867, Nov. 23	Luther
96	Ægle	1868, Feb. 17	Coggia
97	Clotho	1868, Feb. 17	Tempel
98	Ianthe	1868, Apr. 18	Peters
99	Dike	1868, May 29	Borrelly
100	Hecate	1868, July 11	Watson
101	Helena	1868, Aug. 16	Watson
102	Miriam	1868, Aug. 22	Peters
103	Hera	1868, Sep. 7	Watson
104	Clymene	1868, Sep. 13	Watson
105	Artemis	1868, Sep. 16	Watson
106	Dione	1868, Oct. 10	Watson
107	Camilla	1868, Nov. 17	Pogson
108	Hecuba	1869, Apr. 2	Luther
109	Felicitas	1869, Oct. 9	Peters
110	Lydia	1870, Apr. 19	Borrelly
111	Ate	1870, Aug. 14	Peters
112	Iphigenia	1870, Sep. 19	Peters
113	Amalthea	1871, Mar. 12	Luther
114	Cassandra	1871, July 24	Peters
115	Thyra	1871, Aug. 6	Watson
116	Sirona	1871, Sep. 8	Peters
117	Lomia	1871, Sep. 12	Borrelly
118	Peitho	1872, Mar. 15	Luther
119	Althæa	1872, Apr. 3	Watson
120	Lachesis	1872, Apr. 10	Borrelly
121	Hermione	1872, May 12	Watson
122	Gerda	1872, July 31	Peters
123	Brunhilda	1872, July 31	Peters
124	Alcestis	1872, Aug. 23	Peters
125	Liberatrix	1872, Sep. 11	Pros. Henry
126	Velleda	1872, Nov. 5	Paul Henry
127	Johanna	1872, Nov. 5	Pros. Henry
128	Nemesis	1872, Nov. 25	Watson
129	Antigone	1873, Feb. 5	Peters
130	Electra	1873, Feb. 17	Peters

No.	Name of planet	Date of discovery	Discoverer
131	Vala	1873, May 24	Peters
132	Æthra	1873, June 13	Watson
133	Cyrene	1873, Aug. 16	Watson
134	Sophrosyne . . .	1873, Sep. 27	Luther
135	Hertha	1874, Feb. 18	Peters
136	Austria	1874, Mar. 18	Palisa
137	Melibœa	1874, Apr. 21	Palisa
138	Tolosa	1874, May 19	Perrotin
139	Inewa	1874, Oct. 10	Watson
140	Siwa . . . . , .	1874, Oct. 13	Palisa
141	Lumen	1875, Jan. 13	Paul Henry
142	Polana	1875, Jan. 28	Palisa
143	Adria	1875, Feb. 23	Palisa
144	Vibilia	1875, June 3	Peters
145	Adeona	1875, June 3	Peters
146	Lucina	1875, June 8	Borrelly
147	Protogeneia . . .	1875, July 10	Schulhof
148	Gallia	1875, Aug. 7	Pros. Henry
149	Medusa	1875, Sep. 21	Porrotin
150	Nuwa	1875, Oct. 18	Watson
151	Abundantia . . .	1875, Nov. 1	Palisa
152	Atala	1875, Nov. 2	Paul Henry
153	Hilda	1875, Nov. 2	Palisa
154	Bertha	1875, Nov. 4	Pros. Henry
155	Scylla	1875, Nov. 8	Palisa
156	Xanthippe	1875, Nov. 22	Palisa
157	Dejanira	1875, Dec. 1	Borrelly
158	Koronis	1876, Jan. 4	Knorre
159	Æmilia	1876, Jan. 26	Paul Henry
160	Una	1876, Feb. 20	Peters
161	Atho	1876, Apr. 18	Watson
162	Laurentia	1876, Apr. 21	Pros. Henry
163	Erigone	1876, Apr. 26	Perrotin
164	Eva	1876, July 12	Paul Henry
165	Loreley	1876, Aug. 10	Peters
166	Rhodope	1876, Aug. 17	Peters
167	Urda	1876, Aug. 29	Peters
168	Sibylla	1876, Sep. 27	Watson
169	Nelia	1876, Sep. 28	Pros. Henry
170	Maria	1877, Jan. 10	Perrotin
171	Ophelia	1877, Jan. 13	Borrelly
172	Baucis	1877, Feb. 5	Borrelly
173	Ino	1877, Aug. 2	Borrelly
174	Phædra	1877, Sep. 3	Watson

No.	Name of planet	Date of discovery	Discoverer
175	Andromache . . .	1877, Oct. 1	Watson
176	Idunna	1877, Oct. 14	Peters
177	Irma	1877, Nov. 5	Paul Henry
178	Belisana	1877, Nov. 6	Palisa
179	Clytemnestra . . .	1877, Nov. 12	Watson
180	Garumna	1878, Jan. 29	Perrotin
181	Eucharis	1878, Feb. 2	Cottenot
182	Elsa	1878, Feb. 7	Palisa
183	Istria	1878, Feb. 8	Palisa
184	Deiopeia	1878, Feb. 28	Palisa
185	Eunike	1878, Mar. 1	Peters
186	Celuta	1878, Apr. 6	Pros. Henry
187	Lamberta	1878, Apr. 11	Coggia
188	Menippe	1878, June 18	Peters
189	Phthia	1878, Sep. 9	Peters
190	Ismene	1878, Sep. 22	Peters
191	Kolga	1878, Sep. 30	Peters
192	Nausikaa	1879, Feb. 17	Palisa
193	Ambrosia	1879, Feb. 28	Coggia
194	Prokne	1879, Mar. 21	Peters
195	Eurykleia	1879, Apr. 22	Palisa
196	Philomela	1879, May 14	Peters
197	Arete	1879, May 21	Palisa
198	Ampella	1879, June 13	Borrelly
199	Byblis	1879, July 9	Peters
200	Dynamene	1879, July 27	Peters
201	Penelope	1879, Aug. 7	Palisa
202	Chryseis	1879, Sep. 11	Peters
203	Pompeia	1879, Sep. 25	Peters
204	Callisto	1879, Oct. 8	Palisa
205	Martha	1879, Oct. 13	Palisa
206	Hersilia	1879, Oct. 15	Peters
207	Hedda	1879, Oct. 17	Palisa
208	Lacrimosa	1879, Oct. 21	Palisa
209	Dido	1879, Oct. 22	Peters
210	Isabella	1879, Nov. 12	Palisa
211	Isolda	1879, Dec. 10	Palisa
212	Medea	1880, Feb. 6	Palisa
213	Lilœa	1880, Feb. 16	Peters
214	Aschera	1880, Mar. 1	Palisa
215	Œnone	1880, Apr. 7	Knorre
216	Cleopatra	1880, Apr. 10	Palisa
217	Eudora	1880, Aug. 30	Coggia
218	Bianca	1880, Sep. 4	Palisa

No.	Name of planet	Date of discovery	Discoverer
219	Thusnelda	1880, Sep. 30	Palisa
220	Stephania	1881, May 19	Palisa
221	Eos	1882, Jan. 18	Palisa
222	Lucia	1882, Feb. 9	Palisa
223	Rosa	1882, Mar. 9	Palisa
224	Oceana	1882, Mar. 30	Palisa
225	Henrietta	1882, Apr. 19	Palisa
226	Weringia	1882, July 19	Palisa
227	Philosophia . . .	1882, Aug. 12	Paul Henry
228	Agatha	1882, Aug. 19	Palisa
229	Adelinda	1882, Aug. 22	Palisa
230	Athamantis . . .	1882, Sep. 3	De Ball
231	Vindobona	1882, Sep. 10	Palisa
232	Russia	1883, Jan. 31	Palisa
233	Asterope	1883, May 11	Borrelly
234	Barbara	1883, Aug. 12	Peters
235	Carolina	1883, Nov. 28	Palisa
236	Honoria	1884, Apr. 26	Palisa
237	Cœlestina	1884, June 27	Palisa
238	Hypatia	1884, July 1	Knorre
239	Adrastea	1884, Aug. 18	Palisa
240	Vanadis	1884, Aug. 27	Borrelly
241	Germania	1884, Sep. 12	Luther
242	Kriemhied	1884, Sep. 22	Palisa
243	Ida	1884, Sep. 29	Palisa
244	Sita	1884, Oct. 14	Palisa
245	Vera	1885, Feb. 6	Pogson
246	Asporina	1885, Mar. 6	Borrelly
247	Eukrate	1885, Mar. 14	Luther
248	Lameia	1885, June 5	Palisa
249	Ilsa	1885, Aug. 16	Peters
250	Bettina	1885, Sep. 3	Palisa
251	Sophia	1885, Oct. 4	Palisa
252	Clementina . . .	1885, Oct. 11	Perrotin
253	Mathilde	1885, Nov. 12	Palisa
254	Augusta	1886, Mar. 31	Palisa
255	Oppavia	1886, Mar. 31	Palisa
256	Walpurga	1886, Apr. 3	Palisa
257	Silesia	1886, Apr. 5	Palisa
258	Tyche	1886, May 4	Luther
259	Aletheia	1886, June 28	Peters
260	Huberta	1886, Oct. 3	Palisa
261	Prymno	1886, Oct. 31	Peters
262	Valda	1886, Nov. 3	Palisa

No.	Name of planet	Date of discovery	Discoverer
263	Dresda	1886, Nov. 3	Palisa
264	Libussa	1886, Dec. 22	Peters
265	Anna	1887, Feb. 27	Palisa
266		1887, May 17	Palisa
267		1887, May 27	Charlois
268		1887, June 9	Borrelly
269		1887, Sep. 26	Palisa

JUPITER.—Jupiter exhibits a very large disc, and one replete with detail and interesting variations. The flattening at the poles is very obvious, amounting to about $\frac{1}{17}$. The most noticeable features of the planet are the dark and light zones, called belts, running in a common longitudinal direction across the surface, and the four satellites, visible in any small glass, and arranged in nearly the same line as the equatorial belts.

These belts, while constituting the principal aspect of Jovian scenery, are yet variable amongst themselves, and in the appearances, more or less permanent, which are evolved from them from time to time. There is, indeed, no other planet which produces such a great diversity in detail and in the changes, often very rapid, in which they are concerned. The general disposition of the leading belts appears fairly permanent, so that there is sometimes little change apparent from one opposition to another; but when we consecutively examine the minor forms we immediately become aware of their evanescent character, and of the fact that they display proper motions, which in certain cases it is feasible to determine with a very close approach to the truth. Objects near the equator, which during the last few years have mainly consisted of dark and bright spots, rifts, and indefinite cloudy forms of various tints, appear uniformly to be moving much

swifter than objects situated nearer the poles, but there is no regular decrease in the rate of velocity relatively to the latitudinal distribution of the markings. Indeed, the most extreme motion of which we have conclusive records occurred in the instance of some black spots which accumulated along a belt about 25° north of the equator during the autumnal months of 1880. These gave a period $9^{h.}\ 48^{m.}\ 0^{s.}$ The motion of a brilliant white spot near the equator, which has been sedulously watched for five years, shows a period of $9^{h.}\ 50^{m.}\ 9^{s.}$, and a large red spot lying immediately S. of the great southern dark belt has given a mean period of $9^{h.}\ 55^{m.}\ 37^{s.}$ from observations ranging over the last seven years. And it is curious these several markings evince periods gradually increasing with the time. The extent of this in regard to the red spot will be apparent from a comparison of the rotation periods it has given during seven oppositions.

Length of observations	Number of rotations	Period of rotation
		h. m. s.
1879, July 10; 1880, Feb. 7	512	9 55 34·2
1880, Sep. 27; 1881, Mar. 17	413	9 55 35·6
1881, July 8; 1882, Mar. 30	640	9 55 38·2
1882, July 29; 1883, May 4	674	9 55 39·1
1883, Aug. 23; 1884, June 10 and 12 . .	710	9 55 39·1
1884, Sep. 21; 1885, July 8	700	9 55 39·2
1885, Oct. 25; 1886, July 24	659	9 55 41·1

Contemporary with the decadence of the spot in 1882, its velocity seems to have shown no further slackening until the opposition of 1886, when the rotation period increased 2^{s}. During the whole time of its existence it has preserved a uniform elliptical outline, some 25,000 miles long and 8,000 broad, but the tone of the spot has now undergone remarkable modification. All that now remains

of it is a faint pinkish oval outlying the southern belt. It attracted wide notice in the years from 1878 to 1881, from its large size and singular boldness of outline. It was brick-red in colour, and similar to the tint displayed in some of the more prominent belts.

The history of this spot is full of interest, but it can hardly be said of it, notwithstanding its prolonged duration, that the exact period of rotation of Jupiter has been derived from its motion. The velocity of the spot has been carefully analysed to a degree answering every expectation, but there is no doubt this object is a mere atmospheric effect, and not a formation on the actual surface of the planet. Its lengthening of period is conclusive as to its non-stability, and though it may intimate to us a value nearly coincident with the true movement of the sphere, we cannot accept its positions from night to night as perfectly conformable with such material forms as exist on the surface. Nor do the other spots furnish us with more reliable evidence. The white spot effects a change, relatively to the red spot, of $13^{m.}\ 13^{s.}$ (= 8°, or nearly 6,000 miles, on Jupiter) in a single day! And even greater differences have been noticed. How, then, are we to distinguish which form of marking answers most closely with the period which regulates the true ground markings of the planet, which we are pretty safe in asserting have never yet been glimpsed by the human eye?

Only a prolonged study of the phenomena presented can lead us to a solution of the difficulty. My own opinions have changed during the progress of observation, and they lead me to conclude that the red spot with its period of $9^{h.}\ 55^{m.}\ 37^{s.}$ comes far nearer the true period than that of the equatorial markings, embroiled as they are in the commotions and seething vapours affecting this region of

the planet. Their great velocity is accounted for by the swifter currents usually operating near the equator. As to the physical nature of the red spot, it seems to indicate a shallow opening in the dense atmosphere of Jupiter, and the intense red colour of its interior to have represented the dominant hue of the low-lying regions of the actual surface of the planet. And a similar colour in a dark belt is the indication of its depth, and the fact that a narrow zone of the planet's crust is exposed by the action of atmospheric currents. The decadence of these red belts and of the red spot probably result from the filling-in of the vacancies by the more highly reflective vapours of the outer envelopes. Could a definite mark have been distinguished in the interior of the red spot, and had this mark exhibited a proper motion carrying it from one side of the pot to the other, we should probably have had a correct intimation of the true rotation period of Jupiter. As it is, this element is somewhat doubtful, though there is very strong reason to suppose that it is little shorter than the period assigned to the red spot.

From what we have suggested it would seem conclusive that the surface of Jupiter is really of a more intense deep-red colour than Mars. The greater reflective power of Jupiter is caused by his denser atmosphere. Mars has a very attenuated atmosphere, hence his visible colour proceeds from his real surface, and his observed lineaments are those of permanent ground markings. Jupiter shines with an undue brightness relatively to the reflecting capacity of his real surface, and his visible tints and markings are merely atmospheric and temporary. Were Jupiter denuded of his atmosphere and presented in his material aspect, we should recognise a great decrease of brilliancy, and the planet might be seen as a dull red body, in which perhaps

would be distinguished some curious features, especially in the form of bright markings, which would come out very plainly and with greater perspicuity than those of Mars, should any exist independent of atmospheric origin. The red belts and red spot look very dark by reason of the marked contrast with the strongly reflective atmosphere which environs them, similarly to the third and fourth satellites of Jupiter, which are visible as dark spots when projected on the disc, though shining brightly enough when clear of the planet. In a very great measure the transformation is due to contrast, and the absence of an atmosphere involving these moons must be admitted. But the second satellite is never seen dark, because it undoubtedly has a dense atmosphere enabling its surface to vie with the reflective brilliancy of its primary.

There is ample work coming well within the facilities of amateurs in regard to the markings on Jupiter. The fading away or resuscitation of belts and spots should be carefully recorded, and the individual positions of such objects determined. The definite spots should be timed as they pass the central meridian. Differences in their native velocities will thus become obvious, and their degree admits of precise computation if the observations are maintained during the greater part of an opposition, or, better still, if the markings are sufficiently permanent to be followed during several oppositions. The main features are readily revealed in a very moderate telescope, and there is certainly no other planet of our system which displays a series of such wonderful phenomena. The perspicuity with which the details are observed under the exquisite definition of small instruments ought to be utilised by amateurs as a most attractive field for their labours.

The vagaries shown by the atmospheric markings of

this planet, and the attention which they have attracted during the last few years, unquestionably indicate that Jupiter will be the centre of some important discoveries in the future. The systematic observation of objects as they cross the central meridian, and of their changes of outline, distinctness, and tint, will prove of the utmost value. A large mass of data of this kind will enable certain phenomena, at present shrouded in the greatest mystery, to be explained, and the changes now regarded as very irregular may be reduced to definite periods of recurrence. The delineations of this planet at different epochs include formations very suggestive of affinity, and it is for future observers to determine whether these objects are really identical. This may be attained by proving a similarity of form, of period, of size, and of position in two features which may possibly be separated by void intervals during which no connected observations have been recorded; or, more certainly still, by recording an object through all the vicissitudes of a prolonged existence, during which it may disappear and reappear, assuming nearly the same aspect as before, and it will be seen whether the variations are such as may be entirely attributed to atmospheric origin. It is fortunate that the red spot has furnished us with a most eligible object for a persistent research of this kind, and that its developments are being watched by several observers not unmindful of the important issues involved.

Jupiter is subject to a slight phase when in quadrature, but it is so trivial as to be scarcely obvious. The planet's equator deviates little from the plane of the ecliptic, so that the belts are almost uniformly seen running in nearly straight lines across the disc, and far from exhibiting the same elliptical curves as those on Saturn. As a rule, the telescopic view of Jupiter is less satisfactory than that of Saturn, and high powers seldom give a thoroughly sharp

image. This is in part due to the excessive glare, but can hardly be entirely explained on such an assumption. The central region of the planet is far the brightest, and here the dark belts are perceived to their greatest advantage. As they come immediately up to the margin, they are rendered indistinct and apparently distorted beyond sharp recognition.

Observers who make the features of this, or indeed any other planet, an especial study will remember that they are viewing a sphere and not a flat disc; hence objects, as they are distinguished in successive positions, assume different proportions as the effects of perspective. In the instance of Jupiter this is markedly the case, as the very rapid rotation occasions displacement of the objects and apparent changes in their shape at very short intervals. There is another element of discord in such work, namely, the variable state of our own atmosphere. Alterations in the adjustment of telescopes, which often incidentally occur without our knowledge, may also introduce supposed changes in the outlines or distinctness of details. Under these influences planetary markings will sometimes exhibit surprising anomalies from night to night. The careful observer will, however, with experience, be able to dissociate these misleading effects from such physical variations as may really take place from time to time.

The four satellites of Jupiter were discovered in January 1610. Their distances, periods, &c. are as follows:—

Name	No.	Sidereal period	Daily rate	Distance from ♃		Diameter	Brightness
		d. h. m. s.	°	miles	radii	miles arc	
Io	I	1 18 28 36	203·41	267,000	5·9	2,400 1″·081	0·961
Europa . . .	II	3 13 17 54	101·29	425,000	9·4	2,100 0″·910	0·970
Ganymede . .	III	7 3 39 36	50·23	678,000	15·1	3,400 1′·537	1·000
Callisto . . .	IV	16 8 5 7	21·49	1,193,000	26·5	2,900 1″·282	0·820

As these satellites move in orbits nearly coincident with the plane of the Jovian equator, which itself is little inclined to the ecliptic, it is evident that they must frequently suffer eclipse from the shadow of Jupiter, and that they will be often occulted by the planet and also transit the disc. These phenomena are of extreme interest and importance, and come readily within the capacity of small telescopes. The transits both of the satellites and their shadows are especially worth recording; the eclipses come more generally under the routine work of the professional observer, and the occultations are chiefly attractive from the fact that it is alleged the satellites have been occasionally seen just within and through the limb of the planet. The fact is attested from several independent sources, similar to the phenomena attending occultations of stars by the Moon, but it must be confessed the point is one requiring further evidence. The margin of Jupiter is usually rather indefinite from air tremors, and such an occurrence as a satellite hanging upon the limb could only be clearly distinguished with the most extreme steadiness of the image.

The aspects of the satellites while in transit show some curious anomalies, and there are also some surprising variations in their apparent brilliancy when free of the disc, which have suggested the inference that they are very feebly reflective, and probably diversified with dark spots. Indeed, these have been actually seen and delineated by several observers, who do not appear to agree, however, as to the particular forms of the spots. The third satellite in transit becomes a dark brown spot, and the fourth is nearly black; the first assumes a grey tint, and is distinctly visible anywhere near mid transit, but the second can rarely, if ever, be distinguished except as a bright spot. The third

and fourth satellites are usually so dark in transit that they have often been mistaken for the shadows; the fourth is undoubtedly the deepest in tone, and has been described as intensely black, but this is erroneous. When this satellite and its shadow are on the disc at the same time, it is seen the satellite is perceptibly lighter than the shadow, which appears quite black. But if we had a further means of comparison in the shape of an absolutely black disc on the planet, it would be seen that even the shadow scarcely merited the description applied to it. No doubt both the two outer satellites look black contrasted with the bright central region of Jupiter, but they are not as dark as their shadows, and the mistake is occasioned by the absence of a means of comparison.

These dark transits of the satellites are probably due to the presence of large dusky markings on their surfaces, similarly to those which extend over certain regions of the Moon. In the case of the third and fourth satellites, there is no atmosphere to hide these markings, and but an attenuated one surrounding the first. But the highly reflective power of the second satellite, and the pale, indistinct character of its shadow, induce the conclusion that it has a dense atmosphere enabling it to reflect the sunlight in equal degree to its primary.

SATURN.—This planet, though accompanied with a unique system of luminous rings, and displaying belts and a retinue of eight attendant satellites, is yet scarcely so attractive an object for study as Jupiter.[1] Saturn is a

[1] Many observers will be prepared to dispute this assertion. Thus to Prof. R. S. Ball 'it has always seemed that Saturn is one of the three most interesting celestial objects visible to observers in northern latitudes,' the two others being the great nebula in Orion and the star cluster in Hercules.—ED.

splendid object in a good telescope, but frequent observation of his features induces monotony, as there is little to relieve the impression of sameness which the image gives. There is but slight positive evidence of rapid changes similar to those so readily discerned on Jupiter. No doubt the greater distance of Saturn is in a large measure responsible for this obvious want of variety in his observed aspect. We may, indeed, fancy variations in the faint outer divisions in the ring, and catch glimpes of striation in different parts of the ansæ; we may infer a changeable aspect of the interior crape-ring, and often become impressed with the eccentric position of the ring system relatively to the ball, but these and many other curious features of detail are rarely more than mere supposition. Scarcely any two observers will agree in such observations; indeed, it may be safely said that the more delicate forms of the Saturnian system have induced more discrepancies in published records than any other planet of the solar system. Yet Saturn is usually sharply defined, and it is somewhat difficult to explain the conflicting statements which are put forward from time to time. But there is no question that the main cause exists in the variable condition of our atmosphere, and in the too hasty assumption, on the part of certain observers, of peculiarities which must disappear under carefully renewed scrutiny. The rippling which pervades the whole system of rings and is nearly always obvious, especially so under high magnifiers, has the effect of superposing one part upon another, and thus we readily receive impressions of stria and other minutiæ which are really deceptive. Even when the air is fairly steady these refractory displacements will be seen in incessant play about the planet. As to the interior dusky ring, that also is subject to apparent changes according to the transparency

and steadiness of the air-currents prevailing at the hour of observation. In fact, there is no part of this wonderful orb but what is visibly affected by such tremors, and to a far greater extent than many are led to suppose. Large apertures are, however, chiefly concerned in their production.

The best means of nullifying the erroneous impressions caused by distorted or spectral appearances of detail, when the seeing is imperfect, is by reobservation at a more favourable period. Any suspected peculiarities should be carefully examined on several nights, and, should they maintain a distinct indelible outline, we may feel assured of their absolute existence and announce them without fear of being controverted. It will generally be found that abnormal appearances disappear under habitual scrutiny.

The extremely delicate character of the ring system and the somewhat faint aspect of Saturn under high powers are a fruitful source in giving us suspicions of detail not steadily seen or in fact really existing. We should, therefore, be uniformly on our guard against illusions of this kind, and test first impressions by that safeguard of accuracy to be found in frequent reobservation.

The next good opportunity for studying the ring system will occur in 1907. On that occasion the sunlight will illuminate the opposite side of the ring to that presented towards the Earth. Powerful telescopes are necessary under such circumstances.

With regard to the nature of Cassini's division, an observation is possible—under rare conditions, however—which would settle the question as to the dark line being a real split in the ring or merely a portion of it composed of materials with a smaller capacity for the reflection of

light. It has been suggested that on the occasion of the occultation of a star by Saturn the appearance or non-appearance of the star through the division would afford the desired evidence. A star of very small magnitude would scarcely be suitable, owing to the danger of its light being totally overwhelmed by that of the closely proximate ring. Ordinary instruments might be used for the observation, but the opportunity of making it depends upon so many circumstances that the duplicity of the ring may be demonstrated by other means before a chance of trying this crucial test presents itself.

The belts of this planet are apparently fainter than those of Jupiter, and do not exhibit nearly the same amount of detail. In any case we cannot distinguish the same variegated nature. When the air is very clear and steady, the eye will sometimes receive the intimation of feeble gradations of light and shade on the chief equatorial dark belts, but nothing beyond this is certainly visible. The belts seemingly preserve a nearly even tone throughout, with no definite spots or breaks to disturb their continuity. The southern narrow belt, recently so much observed, has been described as 'a string of clouds,' but this has been arrived at by an imaginary process. There are no condensations of conspicuous character upon the belt, and observers are almost unanimous in according it a smooth aspect throughout its circumference. The writer has seen this belt very distinctly in a 2½-inch Ramsden refractor, power 94, which also shows Cassini's division in the rings, so that some of the principal details of this planet fall within the range of very small instruments. In my 10-inch With-reflector, the most efficient power for Saturn on a good night is 475, and the image is fairly good with 641, but too faint for the delicate markings. With 252

the planet is very sharp and bright, but hardly large enough for critical scrutiny.

Only two independent values for the rotation period of Saturn have ever been obtained, namely, by W. Herschel of $10^{h.}\ 16^{m.}\ 0^{s.}4$ in 1794, and by Professor A. Hall in 1877 of $10^{h.}\ 14^{m.}\ 23^{s.}8$. It will be observed there is a difference of $1^{m.}\ 36^{s.}6$ in the two estimates. Professor Hall's, deduced from the returns of a bright spot, is likely to be very accurate, as he gives the probable error of his determination as only $2^{s.}30\pm$. Herschel's period was derived from differences in tone of a quintuple belt visible between November 11, 1793, and January 16, 1794, and he stated his belief that the result could not be in error as much as two minutes. It is probable that neither of these periods conforms exactly with the motion of the sphere, as the objects whence they were derived were evanescent phenomena of the planet's atmosphere. Proper motions will doubtless affect the different belts and spots (the latter are rarely distinguished, as we have already mentioned) on Saturn, and possibly occasion the same remarkable discordances in the rotation periods given by the markings on the surface of Jupiter.

A great necessity exists for the further investigation of the visible aspect of the ball of Saturn. The appearance of any feature which might be utilised for rediscussing the rotation period should be noted as frequently as possible, and the specific times of its central transits estimated with all due care. But it is only rarely that a marking having a distinct terminal in longitude is discovered, though the paucity of such observations may result from the comparative inattention bestowed upon such phenomena, even when they are alleged to have been seen.

The disposition of the belts vary from year to year,

though it is not known to what extent. Sketches ought to be made at every opposition, exhibiting the relative positions and intensities of these lineaments. It is also advisable to preserve records as to the visibility of the inner crape-ring and of the slender division in the outer ring, formerly observed by Kater, Encke, and others. By this means variations might be ultimately detected and a valuable and ready means of comparison afforded to future observers. The certainty and faithfulness of such records must constitute one of the aims of future observers.

The poles of Saturn are compressed even greater than those of Jupiter, and the fact is most palpable when the rings are turned edgeways to the earth. A curious distinction of figure described as a 'square-shouldered' aspect of the planet has been occasionally noticed, but this results from the alternation of the dark and light belts. A broad, luminous zone in high latitude, circumscribed by dark belts, will evidently give that apparent shouldering out of the disc such as observers have recorded.

This planet has more known satellites than any other member of our system. Their distances, periods, &c. are as follows :—

Name	No.	Sidereal period	Daily rate	Distance from Saturn		Discovery
		d. h. m. s.	°	miles	radii	
Mimas . .	I	0 22 37 6	381·99	121,000	3·11	1789, Sep. 17, W. Herschel
Enceladus.	II	1 8 53 7	262·73	155.000	3·99	1789, Aug. 28, W. Herschel
Tethys . .	III	1 21 18 26	190·70	191,000	4·93	1684, Mar. 21, J. D. Cassini
Dione . .	IV	2 17 41 9	131·54	246,000	6·35	1684, Mar. 21, J. D. Cassini
Rhea . .	V	4 12 25 12	79·69	343,000	8·82	1672, Dec. 23, J. D. Cassini
Titan . .	VI	15 22 41 25	22·58	796,000	20·49	1655, Mar. 25, C. Huyghens
Hyperion .	VII	21 7 7 41	16·91	1,007,000	24·81	1848, Sep. 19, Bond-Lassell
Iapetus .	VIII	79 7 53 40	4·54	2,314,000	59·64	1671, Oct. 25, J. D. Cassini

These satellites furnish tests for telescopes of all calibre. The dates of their discovery may almost be said to com-

memorate epochs in the history of the improvement and enlargement of these instruments. The largest satellite, Titan, was detected in 1655, and the last of the series, Hyperion, in 1848, so that the telescope has been occupied nearly two hundred years in revealing the known and probably complete system of Saturnian satellites. Titan is very bright and visible in any small glass; Iapetus is also an easy object, but Tethys, Dione, and Rhea require pretty good instruments. Enceladus is somewhat difficult. Mimas and Hyperion are only to be seen occasionally in the largest telescopes. It is impossible to notify the definite apertures which ought to show these objects under ordinary conditions. Opinions greatly vary on this question. Much depends on the aptitude and visual capacity of different observers. One will see with 4 inches what another will miss with 10 inches.

As to the interior satellite Mimas, Sir W. Herschel said: 'Even in my 40-foot reflector it appears no bigger than a very small lucid point.' Mr. Common remarks: 'This satellite is generally visible when clear of the ring; but it is a most difficult object when near the end of the ring, Hyperion being much easier to observe at conjunction.' As to Hyperion, very few observations had ever been obtained until the great Washington refractor of 26-inch aperture was set to the work. Professor Hall's results proved that the orbit of this satellite is more eccentric than that of any other known satellite, and that in a certain point of its path it may approach very near Titan.

The Saturnian satellites move in orbits but slightly inclined to the plane of the ring, hence when the latter is much inclined, as at the present time, they are scattered round about the planet so that there is some difficulty in readily effecting their identification. The ephemerides of

these and other satellites, annually computed by Mr. Marth, are of the utmost value as enabling their positions to be found at any hour. In every revolution the satellites of Saturn come successively to conjunction with the S. and N. points of the ball, and with the E. and W. ends of the ring. Useful work may be accomplished by watching these phenomena, and recording the exact time of these conjunctions. The data, if exact, will prove valuable in confirmation of the theory of their motions.

Whenever the rings are widely open, as during the last few years, it is obvious that the satellites moving in the same plane cannot exhibit any of the phenomena of eclipses, occultations, and transits which are invariably observed in connection with the Jovian moons. But at intervals of about fifteen years, when the rings and orbit planes of the satellites are presented eyeways to the Earth, we may observe all these occurrences in progress. The shadow of Titan was seen in transit by Sir W. Herschel in 1789, and by later observers in 1833, 1862, and 1877 and 1878, but we must await the somewhat similar opposition of 1892 before such phenomena will admit of repetition.

URANUS.—Uranus is distinctly visible to the naked eye, and at opposition shines like a star of 5½ magnitude. His immense distance renders his disc faint, small, and unattractive, though the planet is really of immense size relatively to the Earth and other planets near the Sun. We know little or nothing, therefore, of the peculiarities of his surface markings, and only four satellites out of a probably large number have yet come within our certain cognisance. Faint belts analogous to those displayed by Saturn are just discernible stretching across the pale blue disc, but the time of rotation is involved in great doubt. Several guesses have been made upon meagre and uncertain

evidence, and we can easily understand the difficulty in obtaining data sufficiently precise to enable the point to be settled. The disc is not often sharply defined in a telescope, and there is little hope of reaching any detail with sufficient distinctness to aid us, unless some of the very large refractors now being constructed are directed to the work.

Uranus has four satellites which are positively known to exist, though Herschel obtained glimpses of what he considered to be several others; but recent observations have disproved his results, and show that they were to be attributed to very faint stars in the immediate region of Uranus. The distances and periods of the known satellites have been very exactly ascertained, like those of Jupiter and Saturn, from a long series of observations and are as follow:—

Name	No.	Sidereal period	Daily rate	Distance from Uranus		Discovery
		d. h. m. s.	°	miles	radii	
Ariel . .	I	2 12 29 21	142·84	123,000	7·44	1847, Sep. 14, W. Lassell
Umbriel .	II	4 3 28 8	86·87	171,000	10·37	1847, Oct. 8, O. Struve
Titania .	III	8 16 56 25	41·35	281,000	17·01	1787, Jan. 11, W. Herschel
Oberon .	IV	13 11 6 55	26·74	376,000	22·75	1787, Jan. 11, W. Herschel

NEPTUNE.—This body forms the latest addition to our knowledge of the major planets, and is the most remote of them all. He is far beyond reach of the unassisted eye, and his disc, even smaller and less well defined than Uranus, is seldom observed except from motives of curiosity. The single satellite known to revolve around him was discovered by Mr. W. Lassell on October 10, 1846, only seventeen days after the planet itself had been detected. This satellite has a period of $5^d\ 21^h\ 3^m$; its daily motion through the orbit is 61°·09, and its distance from Neptune some

220,000 miles. It must be unusually brilliant to have admitted of detection from the immense distance at which it is situated from the earth.

The discovery of Uranus by Herschel was effected during a systematic review of the heavens, and that it was quite unexpected is evident from the fact that its true character was not ascertained until some time afterwards. The detection of Neptune was brought about by a profound mathematical analysis of the perturbations of Uranus, and the credit of this unique achievement is divided between Le Verrier and Adams. Galle at Berlin was the first who verified the actual existence of Neptune by direct observation, after the position had already been indicated, so that in this case the telescope was merely employed as a means of practical corroboration.

No doubt, with the giant telescopes of the future, many new satellites will be found belonging to Uranus and Neptune. We may depend upon it that efforts in this direction will not cease to occupy attention. The field is a prospective one for fresh discoveries, apart from the great interest attached to our knowledge as it now stands.

W. F. D.

CHAPTER VI.[1]

COMET-SEEKING.

THE English climate is admittedly bad for astronomical work, but it comes in for an amount of abuse which far exceeds the justice of the case. Every failure is attributed to bad weather; and the meagreness of results finds this a ready excuse when often the observer himself is at fault. A man who constantly awaits his opportunity early and late, and has made provision for the exigencies of a possibly hurried observation, will seldom have cause for complaint. Disappointments there will be, it is true, especially as regards occasional phenomena; but in regular systematic work he will find plenty of suitable weather to utilise for special ends. The climate in which Herschel was enabled to make such a vast number of important observations is not nearly so deplorable as it is the custom to describe it, though that great observer himself admitted his belief that there were not more than 100 hours per annum when really first-class definition could be obtained. But this has little significance in reference to the work of comet-seeking, because definition, either of the atmosphere or telescope, is not of much moment; all that is really essential is a clear sky; the darker and purer the air, the better it is for the purpose.

[1] This chapter originally appeared in the *Observatory*.

Opinions are divided as to the most suitable aperture and power for this work. Very large instruments are not often used, because of their necessarily restricted fields. Moreover, a small instrument, apart from its advantage in this respect, is worked with greater facility and expedition. This is important, especially when the observer is to examine the region in the immediate neighbourhood of the Sun. He has then a very brief interval for the attainment of his purpose, and a small telescope must be used on account of its large field, its ready manipulation and general effectiveness on objects at low altitudes. The case is somewhat different when the search is to be conducted in regions far removed from the Sun's place, for here the comets are in general faint, and there is time for the work to be deliberately and critically performed. Large instruments are to be recommended for these districts as capable of revealing fainter objects, though they are troublesome in several respects. They show large numbers of nebulæ, especially if the observer is exploring the region of Virgo, Coma Berenices, or Ursa Major, and he will have great difficulty in identifying them and in feeling his way with certainty. These complications are inseparable from the work, and, though chiefly affecting large apertures, should not always be shunned, for a telescope capable of displaying very faint nebulæ is also capable of showing faint comets.

Many comets have eluded discovery by the inadequate reach of the instruments in the hands of comet-seekers; and the statement recently made that there are only about one hundred nebulæ liable to be mistaken for comets is not accurate, because comets in certain positions are of the last degree of faintness, and there is no identifying them from one or other of the thousands of small nebulæ, except by means of their motion. It is said that Messier

discovered all his comets with a $2\frac{1}{2}$-inch refractor, having a power of 5 and field of 4°. His natural keenness of vision and great diligence could only have rendered him so successful with these inferior means.

The summer months are the most suitable for the detection of new comets, notwithstanding an opposite statement by Guillemin ('World of Comets,' p. 16, English edition): 'By an examination of the monthly distribution of the comets according to the dates of their perihelion passages—that is, of the times when they occupy that portion of their orbits in the vicinity of which they are most visible—Arago has found that out of 226 comets the distribution is 130 for the winter months and 96 only for the summer months. Now such a difference can only arise from one cause, and that a very natural one, viz. that the nights in winter are long and favourable to lengthened observation of a much greater portion of the heavens, whilst in summer, the nights being much shorter and further diminished by the long twilight, it necessarily follows that a greater number of comets will escape detection.' But this is altogether erroneous; for, from a monthly analysis of all the comets, periodic and sporadic, discovered during the century 1782–1881 inclusive, I find that the months of August and July are the most prolific of all, whilst June is also slightly above the average. Next to August and July, the months in which observers have been most successful are November, April, December, and June. In May the minimum is reached, and the months of March, September, January, February, and October show a nearly equal proportion; and the average individual number of discoveries during these six months scarcely exceeds one half the average of July and August. In fact, the figures show a most decided maximum at the latter epoch, and it

is curious that the observations of shooting-stars show a very similar distribution. More meteors have been catalogued in August, July, and November than in any other months of the year; and the months of minima are May and March—which is also true of the cometary discoveries of the past hundred years, though the two phenomena may have no distinct connection as regards this similarity of grouping. The predominance of comets in August and July can be accounted for as follows:—

I. Nearly all the comets have been discovered at Marseilles and at other stations in the northern hemisphere; hence, in summer, comets (hovering about near the Sun as a focus) are more frequently above our horizon.

II. The shortness of the nights and prevailing twilight are more than compensated for by more open weather and increased facilities for observation. Moreover, there is a far greater probability of success, owing to the proximity of the Sun to the horizon even at midnight, which renders the northern sky at low altitudes a most prolific region.

III. The work of comet-seeking is more closely pursued at this season, which is free from the great discomforts and trying severity of the winter months.

M. Guillemin's statement that the winter nights permit lengthened observation does not apply, because the whole region in which comets are usually seen is not long above the horizon. In summer, though the nights are short and light, there are more comets visible than in winter. These reasons fail to explain the fact why May and September are months of minima, while November and December are much above the average. The following table, referring to the past one hundred years, exhibits the results and the irregularities apparent amongst them:—

Month	Comets found	Per-centage	Month	Comets found	Per-centage
January . .	17	6·8	July . . .	29	11·7
February . .	17	6·8	August . .	32	12·9
March . . .	16	6·4	September .	16	6·4
April . . .	24	9·6	October . .	18	7·2
May . . .	14	5·6	November .	25	10·0
June . . .	20	8·0	December .	21	8·4

Of 249 comets discovered during the century, 108 belonged to the first six months, while no less than 141 belonged to the last half of the year. As evidence of the rapid increase in the rate of these discoveries, I may mention that during the last five years, 1877–81, 27 comets have been found (annual average=5·4), while during the first 25 years (1801–25) of this century only 38 were seen (annual average 1·5). Grouping the period 1782–1881 into intervals of 20 years, we find the following figures:—

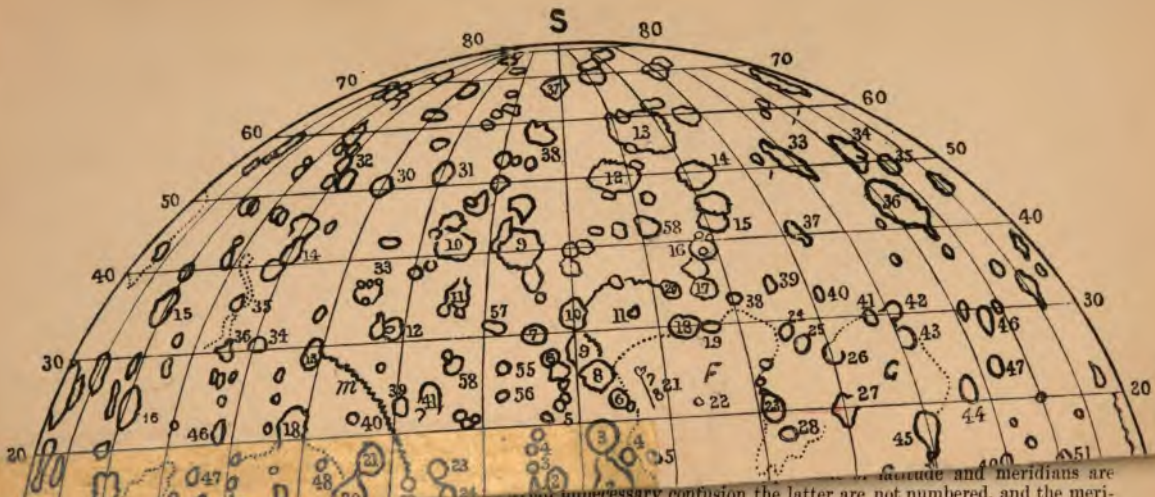
Period	Comets found	Annual average
1782–1801	25	1·25
1802–1821	26	1·30
1822–1841	36	1·80
1842–1861	83	4·15
1862–1881	79	3·95

These discoveries seem to have been greatly accelerated about the year 1845, since which period the rate does not show any perceptible increase. The yearly average since 1842 has been about four.

Though comets are not confined to any special region of the heavens, there is no doubt that the vicinity of the Sun is the spot to which the comet-seeker should direct his chief attention. It is here where the majority of the discoveries have been made; and theoretically this should

be so, seeing that the Sun is the controlling influence of the cometary flights, and that his position must be regarded as a sort of focus of their convergence and divergence. Hence the most likely spots are over the western horizon after sunset and the eastern horizon before sunrise. The twilight and zodiacal light, together with the mist at low altitudes, are impediments which are inseparable from this work; but they need not interfere to any serious extent if the observer is careful to make the best of his opportunity. But though special attention is recommended to the neighbourhood of the Sun, other regions should not be altogether neglected, for comets are occasionally found in nearly the opposite part of the heavens to the Sun's place, as, for example, Swift's comet of November 1881. In order to save time and to prevent troublesome references during the progress of sweeping, the brighter nebulæ should be marked upon a star-chart, so that as they enter the field they may be instantly identified.

Telescopic comets vary in size to a considerable degree. In diameter they generally range from about 1′ to 7′, and are usually round, with a bright centre like the globular clusters M 2, 3, 13, 15, 49, and 92, as seen with a low power; but occasionally they are faint diffused masses like the planetary nebula near β Ursæ Majoris, M 97. In brightness they range from being visible to the naked eye to objects of the last degree of faintness. They average some 2′ or 3′ diameter, but are sometimes less than 1′, so that the power of the sweeper should be capable of readily showing an object of this size as it passes through the field. The ring nebula in Lyra (M 57) between β and γ is a pretty good test. It is a bright elliptical nebula, subtending an angle of some 80″ at its major axis. This object should be brought into the field as a test-object, for



[illegible] latitude and meridians are [illegible] and unnecessary confusion the latter are not numbered, and the meri- [illegible] The Roman capitals indicate the various Maria, the small letters the mountain ranges, and the numbers the principal formations referred to in the text, the numbering in each quadrant being independent of that in the adjoining one, as shown in Appendix I.

To face p. 97.

an instrument failing to show it readily cannot be considered efficient as a comet-seeker. Some other nebulæ should be examined, so that the observer may obtain some idea of what he is likely to see. With my 10-inch reflector (comet-eyepiece) I have often picked up Nos. 4218, 4239, and 4734 of Herschel's catalogue. These are small, pretty bright nebulæ, and certainly ought not to elude detection in an instrument properly adapted to comet-seeking.

No observer should be without the means of determining exact positions. A ring-micrometer and comprehensive star catalogues are amongst the most important accessories of the amateur. When a suspicious object is found, its precise position should be instantly measured; but if no micrometer is at hand, the observer should carefully note the place relatively to adjoining stars, and then after a short interval re-observe it for traces of motion. In these comparisons the low-power eyepiece should be exchanged for one of greater amplification, because this will render a slight motion more readily sensible. If the suspicious object proves to be a comet, the extent and direction of its daily motion should be computed from the change in the observed places, and the information telegraphed to the chief observatories. A statement should also be given as to the diameter and brightness of the object; we may then be satisfied that it will be readily picked up at some of the many stations where prompt attention is given to this class of observation. Amateurs who, like Brooks at Phelps, N.Y., do not profess to obtain exact positions are sometimes condemned for their negligence in this respect, and most unjustly so. By far the hardest part of the work falls to them, and professional astronomers ought to be indebted to amateurs for leaving to their care an important feature of these observations. If amateurs are to undertake the

labour of measuring as well as discovering comets, then there will be nothing left in this line for the elaborate instruments of observatories to do. Yet, while thus objecting to amateurs, with their generally incomplete and inefficient appliances, being expected to perform the work both of discovery and exact observation, it cannot be denied that there is a great necessity for them to have the means of measurement, and to utilise them during the first few observations, which are usually made before the comet has been seen elsewhere, and will therefore possess great value.

Success in this, as in other departments of research, depends, in a very large measure, upon the energy with which it is pursued. To an observer who devotes himself closely to it, and avails himself of every chance presented, there is an encouraging prospect of success; but, on the other hand, a man who looks out at odd times, at convenient hours and seasons, and makes this work subordinate to many other conditions, can hardly regard the outlook as favourable, in view of the diligence with which this branch of astronomy has now been taken up on many hands.

W. F. D.

[There is a comet-seeking organisation in the United States, under the auspices of the *Science Observer*. The Liverpool Astronomical Society contemplates a section for the organisation of this branch of research.]

CHAPTER VII.

DOUBLE STARS.[1]

DIFFICULTIES OF DOUBLE-STAR WORK.—It has been often said the observation of double-stars is a work particularly suited to amateurs, but I do not think the statement can be generally accepted, for several reasons, among which are: A better quality of instrument is required than for most other purposes, as well as an observatory, driving-clock, micrometer, and other accessories of a first-class instrument, which are not always in reach of the amateur; and much more experience is necessary to make a good observer with the micrometer than is required for meridian work, and in most work with the equatorial. There is, perhaps, even now, a greater lack of competent observers in this work than in any other branch of practical astronomy; and it has been so from the first. Altogether, there are not a dozen first-class observers living who can measure accurately such objects as were regularly observed

[1] This chapter is a reprint, with slight alterations, of two papers which appeared in the *Sidereal Messenger*. Mr. Burnham happens to possess exceptional qualifications for the class of work in which he has been so successful, and, as the suggestions he offers are based solely on his own experience, they may not in every case coincide with the opinions and methods of other workers. As a whole, however, they afford an extremely valuable practical introduction to double-star observing.—ED.

by Dembowski and Otto Struve. Of course many can measure with tolerable correctness easy and wide pairs like Castor, γ Virginis, 61 Cygni, &c.; but the time has come when something more is required, and measures will fail to possess that interest and value they would have if the old beaten paths were not so steadily followed. The way in which a large part of the work has been done, with reference to the selection of objects, is much as it would be in another department of work, if astronomers were to keep on observing the satellites of Jupiter, because they are bright and easy, and neglect all the other members of the solar system. A thorough and undivided interest in the work, and constant practice, will lead to steady progress in the class of objects observed, and in the results. It is true that a very considerable portion of double-star work of all kinds has been done by non-professional observers, but as experts they would rank among the highest, and they have acquired their skill by a long course of training. There is room for many more workers in the field, and, with the increasing number of interesting objects, there is no probability of the observations keeping pace with the demands of the work. There is now, and always will be, enough to do for all the instruments, even of very moderate size, that can be given to the work; but it is important that it should be well done. Inaccurate observations will be very soon detected when they are compared with a series of measures over a number of years; and will practically be thrown out, as they should be, in discussing the relative motion or fixity of the components.

THE TELESCOPE.—Whatever instrument is used as to kind and size, it must be of first-rate quality. It is indispensable that the definition should be perfect, or as near perfection as can be attained by the best opticians. If

wanting in this respect, notwithstanding it may show faint stars well enough, it will be best to discard it, and substitute a more perfect object-glass, of even much smaller aperture if necessary. It may be properly said that for this work a telescope is either very good or good for nothing. After unsuccessfully trying star after star which the observer had good reason for supposing could be seen with his aperture, he is very apt to think his vision, though good in everyday use, is in some way deficient for this particular purpose, and is soon discouraged from following up the work. A great deal is charged to the eyes of observers, and to the weather incident to the particular place, which really belongs to the instrument itself.

The instrument must be equatorially mounted, and should have circles of some kind, though they need not be expensive, nor finely graduated. It will answer all purposes if the declination circle is divided to degrees only, as the error in reading or setting the circle by estimation, without a vernier, ought not to exceed 10′, and this is near enough to find any object without trouble, and to identify any pair that is picked up. A corresponding graduation of the hour-circle will be sufficient for getting the approximate right ascension. It is assumed that the adjustments will be carefully attended to in setting up the instrument. There is not the least necessity for an astronomical clock, or chronometer, or any standard time. For all practical purposes, nothing is so convenient as an ordinary watch, used as a sidereal timepiece for the time being. It can be set in a few moments at the commencement of the night's work from the stars themselves, and is then ready for use, when wanted, during the rest of the evening, the difference between its rate and that of a clock keeping sidereal time being of no practical consequence for the few hours which

work would ordinarily be continued. For the purpose of setting the watch, Proctor's 'Handbook of Stars,' which gives the places for 1880 of all bright stars down to the fifth magnitude, is decidedly the handiest. The stars being arranged under their respective constellations, any particular star that is used can be at once turned to, which is not an easy thing to do in an ordinary catalogue where all the stars are arranged in order of right ascension, unless the Right Ascension is approximately known. Webb's 'Celestial Objects' can be used in the same way. We will suppose, on opening the dome, Leo happens to be visible through the shutter; and on turning the telescope on γ Leonis it is found by the R. A. circle to be about fifty minutes west of the meridian. By referring to either of the books above mentioned, it will be seen that the R. A. of that star is $10^h\ 13^m$. Evidently, then, the sidereal time at that moment is $11^h\ 3^m$, and the watch is made to indicate that time. It will be well to repeat the operation (on the same star) to avoid mistakes; and, if necessary, it can be checked again later in the evening. Of course, the watch may be regulated to keep sidereal time if desired.

Particular pains should be taken to see that the object-glass is properly placed in the tube with reference to the axis of the telescope. A very small amount of tilting will put a first-class object-glass on a level with one of very indifferent defining qualities. Selecting a fine night, the appearance of a bright star, near the zenith, under a high power, will show at once whether any change is required. If the star is not round and sharp, and the rings of uniform brightness and appearance, the proper correction should be made with the adjusting screws by raising one side of the object-glass. A single turn of a fine screw will produce a marked effect on the appearance of a close star when

examined with a fine object-glass. In one case it would be difficult to say whether the star was really double at all; in the other it would be beautifully separated, with sharp, clean cut discs.

It has been said that 'a small aperture may sometimes show a very delicate and close companion to a bright star, where a large aperture fails to do it.' This may be true of a refractor and a larger reflector, or of two reflectors; and certainly would be true of an excellent object-glass and a larger one of not good definition; but it is simply impossible with reference to any two first-class object-glasses of the same quality. The power and usefulness of telescopes for difficult double-star work is exactly in proportion to the apertures, other things being equal. The larger telescope will show a difficult object, which it will be impossible for the smaller to show under the same circumstances; and this will be found to be invariably true of all double-stars (and probably of everything else), no matter what the magnitude of the companion is, or its position with reference to the primary. I shall be glad to be informed of any double star, visible with less than six inches, which my instrument of that aperture fails to show, or of any pair which can be seen better with a smaller glass than with any one of the several Clark's refractors I have used in my observations. It may be that with a very unsteady air nothing will be lost by cutting down any large aperture, as difficult objects could not be observed in either case; but I very much doubt if anything will be gained even then with a good instrument. If any improvement is effected under ordinary atmospheric conditions by reducing the aperture of an object-glass or mirror, it may be considered as conclusive evidence that the instrument is a poor one, or, to say the least, of imperfect figure. I have never seen a Clark telescope of any size

which seemed to require the use of any such expedient at any time. Webb says, 'An object-glass of poor defining power may sometimes be improved by stopping out defects or contracting the aperture;' and this is just the result that would be expected with an instrument of that kind; but it would be manifestly absurd, in using a fine object-glass, to expect to see with part of it what the whole would fail to show.

Refractors and Reflectors.—Without attempting to discuss the comparative merits of refracting and reflecting telescopes, it is sufficient to say that the recorded observations appear to indicate that the reflectors which have been much in use, and particularly those of large aperture, are wanting in that perfect definition which is so essential for double-star work. All the difficult double stars now known have been discovered with refractors, and substantially all the micrometrical measures have been made with the same class of telescopes. The catalogues of Sir John Herschel contain a great number of stars classified as double, but, with few exceptions, they are of very unimportant character, and, properly considered, not double stars at all. Close pairs are almost wholly wanting. Although the observations were made with a large reflector, these catalogues contain no stars visible in this latitude which would be a test for a good 6-inch refractor. Indeed, with that aperture, many of the principal stars of these wide pairs of Herschel have been found to be close doubles; hence, in the absence of all test observations, we must conclude, notwithstanding the theoretical advantages often urged, that the figure of the large mirrors most in use during the last half-century was not sufficiently perfect to make them suitable for this class of work. These remarks are based entirely upon what these instruments

have done and have failed to do, as shown by the published observations, and not upon any personal experience with this form of telescope. Some of the comparisons seem to show that with small apertures the difference in favour of refractors is not very great. A single half-hour on any good night would be sufficient with any mirror above 20-inch aperture to make discoveries of new and close pairs, which would show conclusively the character of the instrument with reference to definition. The discovery of a 0·2″ pair would tell more about the value of the instrument than could be learned from scores of testimonials from any source. Whatever opinions may be entertained of the relative importance of double-star work, the statement that the telescope which shows a very unequal and close pair is superior for any purpose to one of the same aperture which fails in such a test will hardly be controverted, notwithstanding the inferior instrument may seem to answer all practical purposes in some kinds of work. The observation of nebulæ has been supposed to be work which any large aperture is good enough to perform, however unsuitable it may be for some other purposes; but it would seem to be quite as important here as anywhere else to have perfect definition, if details are to be correctly drawn and described.

Driving-clock.—A good driving-clock is indispensable in using the micrometer, and very desirable for other purposes, and particularly when high powers are used. With a tangent-screw, position-angles can be fairly measured, but very little can be done with distances without a clock. Bond's spring-governor is perhaps as good a regulator as any yet made; but the new rotary-pendulum clocks, as made by Clark & Sons for their recent telescopes, are much simpler and less liable to get

out of order, and are less disturbed by a varying resistance. Without a steady continuous motion, measures of distance are so troublesome, particularly of difficult pairs, as to be entitled to but little weight. It is frequently stated, as an evidence of the excellence of a driving-clock, that it will hold a star on or near the wire for an hour or more. Such a clock may, or may not, be satisfactory. It is important to know, not what it will do in an hour, but what it will do in ten seconds. A small gaining or losing rate is of very little consequence, provided the motion is steady and uniform from second to second. A clock with an ordinary escapement could doubtless be depended on to hold a star for an hour or two as it was at the beginning, but would be utterly unfit for micrometrical work. A few seconds are sufficient ordinarily for each setting of the wires, but during that time the star and the wire must remain as near as possible relatively fixed.

THE MICROMETER.—It is as important to have a good micrometer as a good object-glass, for on that depends the accuracy of the measures. If a star can be well and certainly seen, it ought to be well measured. It is not enough that the screw should be perfect; and, indeed, this is a very small matter compared with the arrangement for illumination. One can hardly imagine any respectable optician or mechanic turning out a screw so badly made as to lead to any serious or even appreciable error in the short distances usually measured, as most of the work will be within the limits of a single revolution of the screw; but opticians and instrument-makers do not use micrometers, and some of them appear to have strangely erroneous ideas of what is required for the proper illumination of the wires. There must be a provision for bright wires. I am aware that some eminent observers use a bright field exclusively,

and claim for it better results. Such a preference would naturally follow a failure to secure just the right arrangement of light on the wires in colour, direction, and amount. The light must be perfectly under control, and the wires easily reduced to the last stage of visibility when desired. Red light is the best for all objects, faint and otherwise. In the old Fraunhofer plan, the best effect is produced when the lamp is in a plane passing through the micrometer-screw and the optical axis of the telescope. A small change from this position will reduce the light on the wires. The lamp will require to be rotated until it is brought into this position, approximately, for the measure of the angle and distance of each star. I see no reason why not only just as good results should be reached by this method, but in a large class of observations very much better results. Everything depends upon the manner in which the illumination is managed. For bright wires, it is absolutely necessary that the eyepieces should have a cap between the outer lens of the eyepiece and the eye, with an aperture, the size of which depends upon the power of the eyepiece, much smaller than the diameter of the lens.

A much more perfect plan, devised by the writer, has been executed by the Clarks and attached to the micrometers made by them for the Lick Observatory, Mount Hamilton, Cal., and the Washburn Observatory, Madison, Wis. In this arrangement the lamp is attached to the movable part of the micrometer, and is carried around the position-circle by the motion of the wires in position-angle. The light passes through a hole in the end of the micrometer 'box,' and strikes the wires at right angles to them, and of course at right angles to the axis of the telescope. The lamp is so suspended as to be always in a

vertical position, no matter what may be the position or direction of the wires, or the telescope itself. The light is therefore the same, not only in amount, but in direction, so far as the wires are concerned, under all circumstances. By turning the mirror, by means of which the light is reflected into the micrometer, the illumination can be steadily reduced from the maximum amount until the wires become invisible. The field is perfectly dark, as no light can enter the eyepiece, except that reflected from the spider lines. By means of a glass slide, any colour desired can be given to the wires, the intensity of which can be varied at pleasure. A peculiar arrangement of the relative positions of the micrometer screw head, the bisecting screw, and the pinion for rotating the whole system of wires, is also carried out in the micrometers referred to, which is of the greatest value in the saving of time and labour in making measures, and in securing better results by a uniform and naturally convenient method of observing with these two micrometers. I have made during 1881 more than one thousand measures of double stars, many of them of the most difficult class, and I cannot speak too strongly of the great practical value of these improvements. A full description of the micrometer of the Lick Observatory, with an engraving from a photograph, will be found in 'Monthly Notices' of the Royal Astronomical Society for March, 1882.

In attaching the micrometer to the telescope, it should be turned before being clamped in its place, so that the reading of the vernier, when the wires bisect a star in its passage across the field, shall be a little more or a little less than 90°, in order that the quantity to be added or subtracted from the angles taken shall be small, and not require the observed angles to be increased 180°. The micrometer

being left on the telescope, the zero of position will not require to be determined very often.

The movement of the wires for measuring angles should be effected by a pinion, giving quick motion, rather than by a fine tangent-screw. The latter I have found too slow. All of my micrometrical measures at the Dearborn Observatory have been made by turning the frame holding the wires by hand, the tangent-screw and clamp being removed altogether. It is important to place the wires quickly, particularly in measuring difficult objects. When the wire appears to bisect the two stars, the accuracy of the angle can be tested by moving it back and forth with the bisecting screw, placing the stars on each side of one wire, and between the two wires. It would be absurd to adopt any invariable rule for the measurement of either angles or distances. One might as well attempt to use the same power on all stars. The different classes of double stars require different methods in measuring, and experience will be the best guide. The micrometer-screw, in measuring distances, should be turned in the same direction on both sides of the fixed wire. This will eliminate any shake or slack in the screw which the springs may not fully take up. For extremely faint stars near bright ones, a very narrow bar, which can be made of a piece of tinfoil, placed in front of the aperture in the collar holding the eyepiece, will be useful; but it is necessary that the eyepiece should have an independent movement over the system of wires, so that the wires can be placed behind the bar, or on either side of it. With such a provision, found in most micrometers, the presence of a bright star is not a serious objection to accurately measuring the faintest companion. In measuring distances, the bright star will be bisected by one wire, and then by the screw or pinion giving

motion to the eyepiece; the bright star and wire bisecting it are run behind the bar, and the other wire placed on the faint star. The bright star is then run back to see if it is still bisected, and the faint star examined again, and this will be repeated until the observer is satisfied with the result. I have found a bar of this kind much preferable to coloured glass, or any provision for merely reducing the light of the bright star.

In a general way, it may be stated that in measuring stars not exceeding 2″ in distance, the highest power which the night will stand should be used. It will often happen that different powers will have to be used on different nights in measures of the same star. There is no objection to this that I am aware of. Three powers will be sufficient for ordinary purposes. It is sometimes difficult to tell, from any description of a faint companion, what power will best show it. It is well known that some faint stars are only well seen with a high power, and that others, differing in no respect to the eye, are only plainly visible with a very low power.

The amateur observer will not fail to notice a great improvement in his power to see difficult double stars after considerable practice in this class of work. It will not consist so much in any change in the sensitiveness of the eye, as in knowing how to look. Delicate stars will be picked up which in the earlier stage would never be noticed. It is doubtful if there is really much difference in the vision of observers ordinarily, other than that which comes from practice and an intense devotion to a particular line of work. It does not follow because one is successful in finding new stars in regions familiar to the telescope, that he can see more than others, but rather that by training and practice he has acquired the habit of at once detecting

any peculiarity in the appearance of a bright star under examination, if it is a close pair, and of catching any minute point of light in the immediate vicinity. Another observer would perhaps see it quite as well when pointed out to him, but would not detect it independently. The same thing is true in all departments of scientific observation. Discoveries are made every day which it would seem should have been made long ago, but ninety-nine have overlooked what was plain enough to the hundredth passer-by, and was obvious to all when they knew all about it.

OBSERVING-SEAT.—For the measurement of stars at very high altitudes, some sort of observing-seat is very desirable. I have found one made substantially after the plan described by Dr. Erck ('Monthly Notices,' December 1875) to work very well. It is inexpensive, and is easily managed by the observer. The head can be raised and lowered the smallest distance necessary, and measures made with more comfort than even when the telescope is nearly horizontal. Two changes were made in the construction of the seat which it may be well to mention. The legs, with castors attached, were arranged to slide up and down in another set of fixed legs forming guides, so that the whole seat could be raised about two feet above the ordinary position, thus allowing the seat to be used at considerable distances from the zenith. Instead of a pawl and ratchet to hold the hand-wheel in place, a thin piece of elastic wood was screwed to the frame so as to press gently against the rim of the wheel. A slight pressure, which in no way interferes with the turning of the wheel in either direction, is sufficient to firmly hold the movable part of the back in any position. The only drawback to the use of such seats is the inconvenience of reading the micrometer and recording the observations.

For all positions of the telescope, except when the tube is nearly vertical, the observing-seat devised by Professor George W. Hough, an illustrated description of which will be found in 'Monthly Notices' for March 1881, is practically perfect. It is exceedingly simple and inexpensive, is readily moved about on the floor, and the seat can be changed instantly from any position to any other place on the chair. It is far superior in every respect to any plan heretofore suggested. The complicated contrivances which have been in use at different observatories, in which motion is given to the seat by endless chains, tangent-screws, gearing, cranks, &c., are much worse than the roughest and most primitive form of seat that could be thrown together for any work requiring frequent changes of position. The new observing-chair referred to has been thoroughly tested at the Dearborn, Washburn, and Lick Observatories, and has been found to completely answer every requirement.

Lamps.—An ordinary 'bull's-eye' lamp I have found to be superior to anything else for the observatory. It can be closed at once, or, without doing that, the light can be turned to one side so as not to interfere with delicate observations; and for reading circles it is the best and most convenient form. For the micrometer, a lamp with a small round wick, using kerosene, is better than an oil-lamp, as it can be turned up or down in an instant, never needs trimming, and will give a good light as long as a single drop of the fluid remains. It is more easily blown out than an oil-lamp, and on windy nights must be enclosed to avoid annoyance in this respect. If the observatory is supplied with gas, a light rubber tube run up the side of the pier, over the intersection of the polar and declination axles, and then down the tube to the micrometer, will be found

the most convenient, and, if the rubber tubing is properly attached, no reversing or changing the telescope will disturb it.

THE TWO BRANCHES OF DOUBLE-STAR WORK.—It may be stated in a general way that double-star work, to possess any considerable permanent value, must be in one of two directions; first, in discovering new double stars, and secondly, in making micrometrical measures of double stars already catalogued. Of course, by looking up special objects, notes may be made with reference to magnitudes, colours, &c.; but such estimates, unless by observers of considerable experience, have no great value. For the discovery of new stars, an instrument of not much less than six inches aperture will be necessary; but whatever the instrument is with respect to size, it must be of the best definition. If defective in that respect, it will be useless for the purpose. What can be done with a 6-inch aperture, my published catalogues of nearly 500 new double stars will show. This instrument has been dismounted here for the last two or three years, but during a few weeks in the autumn of 1879, when it was set up in California, some forty new pairs were discovered, a number of them being naked-eye stars. The opportunity for the discovery of new pairs is practically as good as it ever was. It is a very rare occurrence in my observations to pick up one of the pairs previously found. All that is necessary for this work is a good instrument and good weather. My experience is, that it is impossible to avoid finding new pairs when prosecuting any line of double-star work under these conditions; and that a pretty good way to discover new systems is not to look for them specially. After making a measure, it has been my practice to examine the neighbouring stars, and particularly those most prominent

in the finder, and in this way I have detected some of the most interesting of those catalogued.

NEW DOUBLE STARS.—Unless the conditions are sufficiently favourable to allow the use of a power of at least 200 on a 6-inch aperture, it will usually be a waste of time to attempt to find anything new. Some judgment should be exercised in reference to what properly constitutes a double star that is really worth preserving. Of course, much depends on the magnitude of the primary, as well as the distance of the components. The extreme limit of distance has been gradually narrowed down in the successive catalogues of new stars. Many of the stars in Sir William Herschel's wide classes are several minutes of arc in distance; Struve rejected all pairs exceeding 32″ in distance; Otto Struve narrowed the limit down to 16″, and in my own catalogues it is still further restricted, except in special cases. Professor Ormond Stone of the Cincinnati Observatory rejects all pairs 'having a distance of more than 32″, or a magnitude for the principal star of less than 8, and the stars having a distance greater than 16″ where the magnitude of the companion is less than 9, unless included in the following formula:—

$$m + m^1 = 19 - \frac{D}{5},$$

where m and m^1 are the magnitudes of the two components, and D the distance in seconds.'

The practical application of this in all cases is not entirely clear, but it seems to me objectionable for two reasons—first, that it extends the limits too far, and secondly, that it discriminates against very unequal pairs, or stars having very small companions, and would, in fact, reject altogether some of the most interesting pairs, however close, where the sum of the magnitude was not less

than 19. I do not see any sufficient reason for varying the limiting distance on account of the magnitude of the companion. One would hardly regard the satellites of Mars as less important than the satellites of Jupiter because they are so much fainter, and certainly would not reject them on that account. There is but a slight chance of finding physical systems where the distance is considerable, and if it be assumed that the brightness of stars is in proportion to their distances, any change due to the proper motion of the bright star could be as well determined, to say the least, by measuring a faint star.

With some experience, the observer will be best governed by the appearance of the pair; but as a general direction I would suggest the following formula as a guide for the selection of new pairs of sufficient importance to be catalogued, m being the magnitude of the principal star, and D the maximum distance:—

$$\left[9{\cdot}3 - \frac{9m}{10}\right]^2 = \mathrm{D}.$$

This formula is the most valuable in its application to the lower magnitudes, and, with rare exceptions, all new pairs exceeding the distance indicated should be discarded. Rejecting small fractions in the telescopic stars, and using round numbers for the bright stars, we have the following limiting distances:—

Magnitude	Distance
10	1·0″
9	1·5
8	5·0
7	9·0
6	15·0
5	25·0
4	35·0
3	45·0
2	55·0
1	70·0

One of the advantages of such a limit is that, with the extreme distances allowed, the small pairs are likely to be quite as important as the brighter. Indeed, a tenth-gnitude pair of stars of 1″ distance would almost certainly be of greater interest than any of the larger magnitudes with half the allowable distance. A 1″ pair should be saved in all cases, however faint the components may be. Of course, a telescope of moderately large aperture will be necessary to detect objects of this class. The double companion to μ Herculis and β 679 are good examples of this class, the last being much the most difficult and the closer of the two. In the large stars new components will necessarily be very close unless they are extremely faint. In the latter case, if distant, they will be interesting chiefly as test-objects. Something will depend upon the magnitude of the large star. Evidently a 30″ companion to Sirius would be of much more interest than a similar attendant to a less prominent star. It may be well to save a distant companion when it is nearer than one previously measured, although otherwise not important. This will happen most frequently in the wide pairs of Herschel I., but occasionally with the Struve stars, which may be outside the limits of distance given here. Such companions, however, will always lack the importance which belongs to a physical system. Most of the interesting binaries will be found in pairs under 2″ in distance, and particularly those in rapid motion.

With practice, and a familiarity with the more difficult stars already known, it is easy to tell what is probably new, even before examining the catalogues. In my 'Third Catalogue of New Double Stars' I have shown that with a 6-inch aperture more than one-third of the stars picked up, which were supposed to be new, proved to be so. With a

larger aperture, the proportion of old stars among those suspected from their difficulty to be new would be still smaller. With the 18½-inch refractor, I think it would be safe to say I can tell at a glance four times out of five whether a pair is new, provided it is not found in some of my own catalogues.

A word of caution may not be out of place with reference to seeing and not seeing difficult objects. It is very common for some observers to speak of 'glimpsing' faint stars. Just what is meant by this term I do not know. Practically it seems to mean, in many instances, that nothing at all is really or certainly seen. One may suspect the existence of a very faint star, or he may see it, but there is certainly no middle course. If it is seen, there can be no doubt about it, and there can be no mistake in the observation; if only suspected, there is nothing to be said about it until that suspicion is verified; and if there is any difficulty in verifying it with the same instrument in repeated trials, it is generally safe to conclude there is nothing there. It is one of the things passing all explanation how any observer, experienced or otherwise, can permanently deceive himself; and still more difficult to understand how another class of persons can see with the greatest ease and certainty the same purely imaginary stars. This happened so frequently in the alleged discovery of companions to prominent stars that one naturally looks with some distrust upon the announcement of new stars confirmed in this way. These discoveries are always made with small or second-class instruments, and generally by astronomers with little or no experience in this kind of work. It is very seldom that double-star observers are deceived, and, when it has occurred, the error has been found and frankly admitted. It is worthy of remark that the observers

who are so successful in seeing stars which do exist never find any real new double stars, and very rarely make any useful observations of difficult objects of any kind within the range of their instruments. It will be a prudent course for the amateur observer when he thinks he has found a new star in the trapezium of Orion, or a new companion to Sirius, Vega, ε Lyræ, or any star likely to have been closely examined before with large instruments, to carefully conceal the observation from his best friends until he is sure of his ground; and, as a preliminary step towards testing the reality of his discovery, let him examine a dozen or more of the most difficult objects of this class about which there is no uncertainty, and see what success he has in seeing them. I think I may venture to recommend as particularly appropriate for this purpose many of the double stars given in my catalogues of new pairs published from time to time, and especially the list given in the 'Memoirs of the Royal Astronomical Society,' vols. xliv. and xlvii. New stars, if they have any existence outside of the imagination of the observer, will always keep well, and the discoverer will lose nothing by delaying the announcement until he has repeatedly verified, and measured if possible, the new object. From the non-observance of this rule, a great deal of time has been needlessly wasted in looking for the supposed new stars, about which nothing should have been said in the first place.

MAGNITUDES.—In the matter of magnitudes, it is much the best to employ the Struvian scale. The fact of its use in all the observations of both the Struves, Dembowski, and other great double-star observers is a sufficient reason for preferring it to any other. In this scale a star of any given magnitude is supposed to have four times the light of a star one magnitude fainter; but the recent photometric

observations of double stars made at the Harvard College Observatory tend to show that practically Struve's magnitudes are about the same as those of a later scale where the light ratio is 2·5 instead of 4. It is sometimes convenient to know what is the faintest star which can be seen with any given aperture. In a general way it may be stated that, if the diameter of a telescope be doubled, its seeing power will be increased one and a half magnitudes. The following table, based upon a light ratio of 2·5, is from Newcomb and Holden's 'Astronomy:'—

Aperture. Inches	Minimum visible. Magnitude	Aperture. Inches	Minimum visible. Magnitude
1·0	9·0	6·5	13·1
1·5	9·9	7·0	13·3
2·0	10·5	8·0	13·5
2·5	11·0	9·0	13·8
3·0	11·4	10·0	14·0
3·5	11·7	11·0	14·0
4·0	12·0	12·0	14·4
4·5	12·3	15·0	14·9
5·0	12·5	18·0	15·3
5·5	12·7	26·0	16·1
6·0	12·9	34·0	16·6

VARIABILITY.—In this connection a word of caution in respect to charging double stars with variability should find a place. All experienced observers, and a great many of the other class, make too little allowance for the 'seeing,' and very frequently ascribe the difficulty of observing a particular star, or the failure to see it, to some mysterious variability in its light. I repeat here what I have more than once asserted before, that in the lower magnitudes there is not a single double star known where there is any satisfactory evidence of the variability of the companion.

Of course, such instances may exist, but I know of no star where the observations, when carefully sifted and compared, even tend to establish it. I am aware of the adverse opinions of some eminent observers with reference to special objects; but I think much of the difficulty experienced in catching these faint stars, if not all, may be attributed to the seeing. For instance, an observer looks at the sixth star of the trapezium with, say, a six or eight inch aperture, and fails to see at all what, on a previous occasion, was very plain, and immediately comes to the conclusion that the star is variable. The fact is that the very best proof in the world of variability would be furnished by always seeing unequal pairs of this class with any moderate aperture. If any one will examine with an aperture of seven or eight inches the double stars discovered with my six-inch, he will find a great many variable double stars, if such a condition can be inferred from an entire failure to see many of them on ordinary or even good nights, and this will be just as true if a still larger aperture is employed. A steady air and good definition are indispensable, and one cannot always tell just how good these conditions must be until a trial is made. There are comparatively few working nights when I do not place the instrument on some star the companion to which I am unable to see; and never, in a single instance, has such failure led to even a suspicion of any change in the star. It is exactly what one would expect if the star was not variable. There is no kind of night which is the best possible for all kinds of observations, even of double stars. I have frequently had stars, which I thought might be double, on my list for examination for many months, and in some instances several years, before I could be absolutely certain they were really double.

It is necessary to keep trying until just the right conditions are found, and then the doubtful star may come out plainly enough.

It has been said that a much larger aperture is necessary to discover a star than to see it when its place is known. It is easily seen how this might be true of persons not particularly accustomed to this kind of work; but it ought not to be true of practised observers, and certainly is not in accordance with my experience. I have never been able to see any sort of advantage from knowing anything about a double star in advance of the observation. A few seconds only are sufficient to examine as carefully as it can be done every quadrant, and to see all that can be seen on that occasion. I have generally seen a faint star of this kind better at the time of its discovery than at any subsequent time, and therefore very early adopted the plan of carefully estimating or measuring the position of the new star when first found.

What has been said about uncertain observations does not apply so well to close pairs as to very unequal ones. In the case of a pair much below the separating power of the telescope, an elongation may be suspected, which a better night or a larger instrument will show is not real. It is well to make a note of such stars, even under ordinary atmospheric conditions, as some of them are certain to prove to be really double. I have discovered a good many objects of this class under such circumstances; and, in some instances, where the pair was very close, have kept it on the list for perhaps a year, examining it on every suitable occasion when convenient to do so, before I could feel quite certain of the duplicity. A very close double star does not look like a single star, even when it is impossible to guess at the direction of the elongation with any

certainty. It would be difficult to describe, or even point out, any peculiarity in the appearance of the star. One is impressed with a difference long before a steady air and high power make an elongation decidedly apparent. In this way I have frequently found stars on an indifferent night which proved to be exceedingly difficult under the very best circumstances. And so, observing with a very small instrument when the very best work can be done within the range of the aperture, stars will be found which do not look like single stars, but it will be impossible to say more with certainty, and they must be examined with a larger aperture. The double stars β 260 and β 291 are examples of what will sometimes be done in this way. The latter pair was for a long time suspected with the 6-inch, and subsequently verified, and found to be a difficult object with a 26-inch aperture.

The highest power is not the best in searching for new pairs, even under the best atmospheric conditions, for although it will show extremely close pairs better than a lower power, it will wholly fail to show other classes of pairs. With a 6-inch aperture, the best general working eyepiece will be a power of about 200. That will show most of the minute stars as well as any other power, and with it the practised eye will rarely pass any pair down to 0·4″ in distance, without suspecting something, and trying a higher power.

Eyepieces.—It will be a great saving of time to have the eyepieces so arranged that when pushed into the adjusting tube they will be in exact focus. This is easily done in this way: push the highest power into the tube as far as it will go, and then focus it very carefully upon a close pair not far from the zenith; then remove this power, and put in the others successively, without disturbing the

tube or touching the focussing screw, and, after getting the exact focus, mark on the side of the eyepiece the precise place of the end of the tube. Then a collar of tin extending to this mark can be fitted in a few minutes which will serve as a stop when the eyepiece is placed in the tube. This collar may be narrow except at two points on opposite sides, which is well to have rather too wide than otherwise, and then work down with a file. Of course an excellent night will be selected for marking the eyepieces, and all possible care exercised in getting the best place for each power. With the eyepieces fitted on in this way, when one is in focus, any other may be substituted without loss of time; and when it may be necessary to do this perhaps fifty times in a night, it is not an unimportant matter. I can speak with the utmost confidence of the practical value of such an arrangement. It is only on very fine nights that any improvement in the focus need be attempted, and then but rarely. When the micrometer is attached, this is already provided for, as each eyepiece, when pushed or screwed into its place, will be focussed on the wires.

Working List.—For micrometrical observations two working lists should be prepared, one containing very close and difficult pairs, and the other wide and comparatively easy pairs, each arranged in order of right ascension. A very convenient arrangement is to put each hour of right ascension on a separate, closely ruled page, and have the leaves cut at the edge like an index, putting the hour on the marginal part of each leaf, so that the book can be opened at once at the desired place. The lists should contain the name, right ascension, declination, angle, distance, and magnitudes of each pair, which should have a place on the page in proportion to its distance from the commencement of the hour. Additions can then be made to

the list at any time, and the stars inserted in their proper places. By arranging and classifying the stars in this way, much time will be saved in finding suitable and convenient objects for observation. In making up the lists, the most interesting objects of each class within the range of the instrument will be selected, and particularly those which have been overlooked or neglected by observers heretofore.

More than 10,000 stars have been catalogued as double, but the number of pairs sufficiently interesting to merit any attention is smaller than is generally supposed. It is safe to say that altogether we shall find less than 3,500 stars within 120° of the North Pole, which, judging from the magnitudes and distances of the companions, are of any considerable importance; and a large number of these have their relations so far determined as to render observations for the present unnecessary.

Record of Observations.—For an observing-book I have used for a long time a common blank book, to be found at any stationer's, about six by seven and a half inches. Any blank book will answer the purpose, but this will be found to be as suitable as any other. A small brass clip, such as is used to hold papers together, is very convenient for keeping the place, as the book can be opened to the right page without a light at once. All printed or blank forms of any kind for double-star measures are worse than useless and of no conceivable advantage. The necessary entries are few and of the simplest possible character, and can easily be put in one-fourth of the space occupied by some of the printed forms which have been suggested, which generally contain places for many things no one should ever think of wasting time by filling up. Perhaps I cannot better illustrate my idea of the most convenient way of

making the entries than by copying the page of my own observations, which shows all that is necessary to put down. This is a portion of my measures made on the last working night, given in the order in which they were made. It is in every respect an exact copy of the original entries, and fairly represents all that is ordinarily written on any occasion.

April 25, 1880·315.

ζ Cancri. ($8^h\ 5^m\ 20^s$.)

5 . . . 5·2 V.

9 : 30	85·5°			
	4·3			85·6°
	4·7	·905	·020	0·64″
	6·2	·900	·014	
	6·0	·908	·014	
	85·3	·904	·016	

Regulus. ($10^h\ 2^m\ 0^s$.)

8·3 . . . 13 II.

	B C 86·5°	49·662	·236	
10 : 20	6·8	·710	·217	87·7°
	7·3	·705	·218	3·63″
	8·3			
	8·0	·692	·224	
	87·4			

Σ 3121. ($9^h\ 10^m\ 46^s$.)

7·0 . . . 7·5 (3rd quad.) V.
Well separated.

10 : 8	24·4°			
	19·0			199·8°
	19·4	·919	·002	9·50″
	18·5	·905	·999	
	19·2	·908	·995	
	19·5	·911	·999	

39 Leonis. ($10^h\ 10^m\ 39^s$.)

6·0 . . . . 11·8 II.

	117.0°			
	7.0			298·4°
10 : 35	9·2			6·91″
	7·5	49·345	·572	
	9·9	·382	·546	
	8·3	·333	·582	
	118·1	·353	50·563	
			49·353	
			1·210	

The right ascension of the star is given in parenthesis following the name, then the estimated magnitudes, and the number of the eyepiece used. In these observations eyepiece V is a power of 900. There is no occasion for inserting the declination. The right ascension is all that is needed for indexing or referring to any catalogue or list. The sidereal time of the observation is written on the left. The footings of the several columns, and the reduced angles

and distances on the right were, of course, made subsequently. The parallel reading of the position-circle at this time is 89·7° ; hence, the mean angles require a correction of +0·3°. The figures in the second and third columns are the readings of the divided head of micrometer screw, in thousandths of a revolution, on each side of the fixed wire. In pairs not exceeding two or three seconds distance, it is not necessary to read or record the number of the revolution, and only one side in any case, the coincidence of the wires, of course, being known. In this micrometer the coincidence is made at 50 on the scale, and, therefore, if the scale reads 49, as in the observation of 39 Leonis, the other side must be 50. The double distance is 1·210 revolution, half of which, multiplied by the value of one revolution (11·42″), gives the measured distance. To facilitate this work, and to avoid errors, a table should be prepared from which the values can be taken at once. The following is a portion of such a table, based upon the value of the screw used in these measures :—

	·000	·001	·002	·003	·004	·005	·006	·007	·008	·009	
·00	—	0·1142	·02284	·03426	·04568	·05710	·06852	·7994	·09336	.10278	·00
·01	·1142	·12562	·13704	·14846	·15988	·17130	·18272	·19414	·20556	.21698	·01
·02	·2284	·23982	·25124	·26266	·27408	·28550	·29692	·30834	·21976	.33118	·02
·03	·3426	·35402	·36544	·37686	·38828	·39970	·41112	·42254	·43396	.44538	·03
·04	·4568	·46822	·47964	·49106	·50248	·51390	·52532	·53674	·54816	·55958	·04
	&c.		&c.		&c.		&c.		&c.		

This is equally useful in reading long distances, due regard being paid to the decimal point. For instance, if the double distance is 10·628 revolutions, we shall have from the table :

5·3	60·526″
·014	·160

Distance = 60·686

The double stars measured above are good representations of moderately close and nearly equal pairs, and very unequal components. Three of these are interesting physical systems. The companion to Regulus was measured for the first time two or three years since. It requires a large aperture, as the companion has not more than one-third of the light of the companion to 39 Leonis (OΣ 523). Many of the later measures of Σ 3121 require a correction of —180° in the position angle.

The measures should be copied into a record book, the page being wide enough to rule the following columns: Current number for indexing; name of star, or designation in Σ, OΣ, &c.; right ascension; position angle; distance; date expressed decimally; sidereal time; power, or eyepiece; the remaining portion of the page being used when necessary to indicate the particular components measured, as B, C, &c., and for other notes. When the first measure of a star is written in, a sufficient number of lines should be left before entering another star, to put in subsequent measures. As a general rule, each star should be measured on at least three nights, and oftener in the case of very important and difficult pairs. The stars should be indexed as fast as they are copied in, for which a book similar to that used for the working list may be used, or a large sheet of paper, folded so as to make at least 24 narrow pages, and then cut and stitched at the back. A sheet of this kind, making a page eight or nine inches in length, will afford room for indexing at least 1,500 measures without much crowding. Of course, only the name of the star, right ascension, and reference number will appear here. The observer can tell instantly whether he has measured any particular star, and, if so, can turn at once to the observations. New double stars should be put in another

part of the book, three or four on a page, leaving sufficient space to put in all subsequent measures.

It will be very rarely necessary to put down in the observing book any more than is shown in the foregoing observations, and on an average the observer will not need to write half-a-dozen words a night. Unless the night is very fine, no entry need be made of stars not seen, or not seen well enough to measure. This will occur very frequently if the more difficult stars are looked for. It may happen once a week that it will be necessary to indicate the quadrant. This will be in measuring pairs where the components are so nearly equal that the angle may be reversed; but it will be important to attend to this only in very close and rapidly moving couples, and particularly when they have been supposed to be recently single. This may be done by a diagram; but much the quickest way is to note, after the magnitudes, either the quadrant or estimated angle. In all other instances the observer will know by the description in his working list whether he has set on the right object, and will notice an error in the direction, if any exists, and will be sure of the identity of the object before proceeding further.

Amount of Work.—The amateur observer may wish to know how much micrometrical work he should ordinarily be able to do. This will depend upon the zeal and industry of the observer quite as much as upon the state of the weather. All large telescopes are, to a greater or less extent, more troublesome to manipulate than small ones. The moving of the dome necessarily requires more time, and fewer stars will be observed than with a telescope of moderate size. One may make fifty measures in a night, but half this number is a good night's work, and the average will be represented by a much smaller number.

The amateur observer, who has other duties during the day, and cannot, therefore, use the entire night for astronomical work, except on special occasions, should make in a year, with the average amount of clear weather, at least one thousand separate measures. If he has leisure, and is free from business cares, he will naturally do much more each night by making longer hours, and in a year should accomplish nearly twice as much. When a first-class night comes, the earnest observer will make the most of it, and will, of course, indefinitely postpone going to bed for a night or two at least. He will prefer to get along with three or four hours a day of sleep for a week, if excellent nights should continue so long, rather than to lose any of the time so valuable; and it is only in this way that very much progress can be made in discovering or measuring difficult double stars. One fine night is worth more than a dozen indifferent ones, because stars can be observed of which a single good measure would be of more interest and value than measures of much greater number of the other class of stars. Hence, if one is going to follow the subject in earnest, he will under no circumstances fail to improve every opportunity to observe a difficult pair. It is always dangerous to put it off for some more convenient time, which may not occur for a year. In the winter, in cold climates, heavy clothing will be necessary, especially for the feet, and there is not much fear of overdoing it, with the temperature much below zero. When the thermometer gets down to ten or fifteen degrees below zero, the observer may find his enthusiasm somewhat cooled off, unless the seeing is very fine.

Methods of Observing.—In measuring the double stars my practice has been to make four or five settings for the position angle, and three on each side for the double dis-

tance. This is in accordance with the practice of some of the best observers. Certainly nothing is gained by making a great number of readings on one night, and there is no reason for expecting any better result from a dozen or twenty measures than from the smaller number. It is easier to make the individual readings agree with each other than to make the mean results of different nights correspond, even when the observations are made apparently under the same conditions. The only way to secure accurate results is to increase the number of nights. Some observers have adopted elaborate plans of assigning weights to each night's work, or getting in some roundabout way the most probable mean result from several observations. It seems to me that nothing is gained, if the measures are properly made, by any such course. By no manipulation can good results be obtained from poor observations, and burying them under a load of least squares, probable errors, and assigned weights will not improve them. It has been said of one authority that he seemed to believe 'that valuable results could be obtained from any data, however imperfect, by using formulæ with an adequate supply of signs of integration.' The best observers simply take the arithmetical mean of the different measures, and this is undoubtedly all that is necessary to be done. If a reasonably good measure cannot be made, it is better not to attempt it; and one can tell about this as well before commencing as three or four minutes later, when the measure has been made.

A preference has sometimes been expressed for measuring certain classes of double stars by daylight, or in the early twilight. Ordinarily, I have not been able to see satisfactorily any difficult stars I wanted to measure until very nearly dark, and have seldom found the images suffi-

ciently steady until about an hour after sunset to make it worth while attempting to make measures. Of course many of the brighter pairs can be seen at any time of the day. I have measured ε Bootis with a 6-inch aperture in broad daylight, and some hours before sunset.

WORKS OF REFERENCE.—For the purpose of identifying double stars, the observer will need the following catalogues :—

1. Struve's great catalogue, 'Mensuræ Micrometricæ.' The reprint of this work, prepared and published by Lord Lindsay, contains the mean results of all the observations, and is much more convenient to use than the original, as the stars are all arranged in one catalogue in order of right ascension, instead of in classes. The re-publication of this great, and now scarce, catalogue in a compact form has been of much service to all interested in the subject.

2. Otto Struve's Pulkowa Catalogue. This is a small work, but fully as important as the other, from the larger proportion of close and difficult pairs. Although it contains less than 500 stars, it will be referred to in identifying objects found from time to time about as often as the other, containing more than six times as many pairs. The revised and corrected edition of 1850 should be used. The stars are given without measures, but with places, magnitudes, and approximate distances. Dembowski's measures of these stars will be found in the *Astronomische Nachrichten*, Nos. 1806–32. The observations of Otto Struve, made since 1840, are contained in vol. ix. of the Pulkowa Observations.

3. The various catalogues of new stars I have contributed from time to time, a list of which will be found in the introduction to the 'Double-star Observations made in 1879–80 at the Dearborn Observatory,' *Memoirs* R.A.S.,

vol. xlvii. These thirteen catalogues comprise 1,025 new double stars, and, as a large proportion of them are difficult objects, they are certain to be picked up by anyone successful in discovering new stars. There are but few stars, relatively, in 'Mensuræ Micrometricæ,' which it will be necessary to stop to identify when found, if one is looking for new stars. Most of those which are not close are too easy with a telescope of much power to be new, and may be safely passed by. For more than 15° south of the Equator, the catalogues of Stone and Howe of Cincinnati will be important, as they contain a considerable number of new stars, as well as measures of pairs but little observed heretofore. There are some other late minor lists of new stars, but, as they contain altogether only a few objects, they need not be specified here. The several catalogues of Sir John Herschel, although they comprise more stars than all the works above enumerated, will be very little wanted. They were picked up in sweeping with a low power, and, with very few exceptions, are faint, wide, and unimportant, and such as would receive no attention from the observers of the present day. All double stars in the catalogues of Sir William Herschel, close enough to bring them within the limit of distances adopted by Struve, will be found in 'Mensuræ Micrometricæ.'

For the purpose of micrometrical work, the 'Handbook of Double Stars,' by Gledhill and others, and Flammarion's 'Etoiles Doubles et Multiples en Mouvement relatif certain,' will be almost indispensable. The former contains much valuable information not to be found anywhere else. The chapters on the telescopes, methods of observing, &c., will be of the greatest service to amateur observers. The catalogue and measures include a large number of the most interesting objects, suitable for all classes of telescopes.

Flammarion's work deals only with stars having relative motion, and gives substantially all the measures, arranged in chronological order, of every pair where there has been any change in the angle or distance of the stars, with notes concerning the character of the motion, periods of binary stars, &c. One can see at a glance just what moving pair most need measuring.

Webb's 'Celestial Objects for Common Telescopes' is too well known to require any commendation. It has done more perhaps than any other work ever published to interest amateurs in astronomical work, and is not likely to be superseded by any similar work. Though founded upon Smyth's 'Bedford Catalogue,' and to some extent indebted to that work, Mr. Webb, in the extracts made, has managed to avoid most of the mistakes which illustrate almost every page of Smyth relating to double stars. The new edition, issued in 1884, contains a large amount of new matter, and should be in the hands of every amateur observer.

Mr. Chambers has recently published a revised and enlarged edition of the 'Bedford Catalogue,' omitting many of the erroneous measures of Smyth, and giving very late measures of the more interesting double-star systems, of which several hundred are given not contained in the original edition.

The numerous series of measures by the various double-star observers are very convenient for reference; but the works I have mentioned will answer all practical requirements of the amateur observer, for some time at least. A general catalogue of double stars is very much needed by all classes of observers, and those interested in the subject, for the identification of stars and for selecting suitable pairs to observe. The so-called Herschel's 'General Cata-

logue of Double Stars' is of no use for any conceivable purpose. It contains about all the mistakes which have ever been made by anyone concerning the stars in question, and, in addition, many others. It omits entirely several hundred of the most interesting double stars, including a portion of the Pulkowa Catalogue, and, as an offset or compensation, includes a large number of stars, perhaps as many more, which are not only not double at all, but have never been suspected or regarded by anyone at any time as double. These defects, however, are of little consequence, and not worth correcting, because, if the work was entirely free from them, and without errors of any kind, it would still be, from the entire absence of all description of the stars and information of any kind concerning them, practically useless. It is unfortunate that this catalogue could not have been prepared by Sir John Herschel.

A good star map is very desirable, and for general observatory purposes I have found Proctor's Atlas better than Argelander's, Heis', or any other with which I am acquainted. Some of the points of superiority are: the method of representing magnitudes; attaching the letter or number to the Flamsteed stars, omitting the constellation figures, thereby rendering the map much clearer and easier to use in comparing it with the heavens, &c. To keep up with the current discoveries and observations, the astronomical periodicals, and particularly *Monthly Notices* of the Royal Astronomical Society, *Astronomische Nachrichten*, *Observatory*, and *Sidereal Messenger*, should be consulted.

Star Catalogues.—For fixing the places of new double stars, certain star catalogues will be necessary. For a single catalogue Lalande's is perhaps the most serviceable,

as it includes nearly 50,000 stars, distributed over the whole area of the northern heavens. For particular regions the following may be named as being likely to contain most of the small stars wanted: within 10° of the North Pole, Carrington's Catalogue; from the Pole to 45° north declination, Oeltzen's Argelander, and Radcliffe; from 45° to 15° north declination, Weisse's first catalogue; from 15° north to 15° south, Weisse's second catalogue, Schjellerup, Berlin, and some of the Lamont Zones; from 15° to 31° south, Oeltzen's Argelander, Lamont's Zones, and Washington Zones. Dr. Gould's recently published *Argentina Uranometria* contains all stars down to the seventh magnitude from the South Pole to 10° north of the Equator, and is invaluable to southern observers. Equally indispensable to astronomers in the southern hemisphere is Stone's 'Cape Catalogue of 12,441 Stars for 1880.' Occasionally stars will be picked up which cannot be found in any of the catalogues mentioned. Reference must then be made to the Zones of Argelander, the three volumes of which contain all the stars down to the ninth magnitude between the Equator and the North Pole, comprising in all more than 324,000 stars. Every observer should have this catalogue to fall back on, and for its accurate determination of magnitudes. The star places are only close approximations, but near enough for all practical purposes. In identifying small stars, and particularly in crowded parts of the heavens, it is best to take the readings of the circles on one or two of the brightest neighbouring stars, as well as the new double star. It will take but a minute or two longer, and will frequently prevent uncertainty when the star catalogues are referred to for the place of the required star.

The foregoing suggestions are such as have occurred to

me in hurriedly going over the subject for this purpose. They are necessarily incomplete, and many points, perhaps equally important, are left untouched. To consider thoroughly in all its bearings a subject of so much magnitude, and of so wide a range, would far exceed the limits of the present article. In conclusion, I would caution the amateur observer against attempting to cover too much ground, or taking hold of too many kinds of work. It is only by persistently sticking to one thing that substantial results can be accomplished. If double-star work is to be taken up, let the Sun, Moon, and other heavenly bodies take care of themselves; or, at any rate, trust them to the observers who are making these objects a special study. It is better for science, and better for the observer, that he should strictly confine himself to whatever branch of observation he may select. Any one of the numerous subdivisions of astronomical work is enough for the whole time and best efforts of any observer. The universe is too vast, and life too short, to undertake more.

S. W. B.

APPENDIX TO CHAPTER VII.

Binary Stars for which orbits have been computed, with the elements obtained by different computers. Compiled by J. E. Gore, F.R.A.S.

Note.—The orbits marked with an asterisk are probably the best hitherto published.

No.	Star	P Years	T	e	γ	Ω	λ	a	μ	Computer
					° ′	° ′	° ′	″		
1	ζ Sagittarii . . .	18·69	1882·86	0·1698	58 48	83 22	263 21	0·53	–	Gore (1886)
2	42 Comæ Beren. .	25·71	1859·92	0·480	—	—	99 11	0·657	–	O. Struve
3	β Delphini . . .	26·07	1882·19	0·3567	54 54	163 34	354 36	0·55	+	Dubjago, 1884
"	" " . . .	30·91	1882·25	0·337	59 20	2 38	327 46	0·517	+	Gore, 1885
4	ζ Herculis . . .	31·4678	1829·50	0·45454	50 53	39 26	262 4	1·189	–	Mädler
"	" " . . .	34·221	1830·01	0·4239	—	45 56	—	1·223	–	Dunér
"	" " . . .	*34·411	1864·78	0·4666	44 32	44 6	251 47	1·345	–	Doberck
"	" " . . .	36·357	1830·481	0·4482	±136 17	—	284 55	—	–	Villarceau
5	Σ 3121	*37·03	1842·78	0·2600	74 15	16 0	149 30	0·71	+	Doberck
"	"	39·18	1850·0	0·3471	—	19 56·4	—	0·696	+	Fritsche
"	"	40·62	1850·0	0·3795	—	23 5	—	0·715	+	"
6	η Coronæ Bor. . .	40·17	1849·9	0·287	60·4	22·2	224·1	0·985	+	Flammarion
"	" " . .	*41·562	1850·792	0·2667	59 41	25 43	218 36	0·918	+	Doberck
"	" " . .	41·58	1850·26	0·2625	58·0	26·7	211·4	0·827	+	Wijkander
"	" " . .	42·500	1807·21	(16° 48′)	59·28	20 6	215 11	0·9024	+	Mädler, 1847
"	" " . .	42·501	1805·666	(28° 19′)	65 39	10 31	227 10	1·0125	+	Villarceau, 1842
"	" " . .	43·115	1850·329	0·2865	60 40	22 18	215 29	0·9567	+	Winnecke
"	" " . .	43·246	1815·230	(19° 44′)	71 8	24 19	261 21	1·0879	+	Mädler, 1842
"	" " . .	43·310	1815·20	(20° 43′)	71·29	22 35	263 10	1·1912	+	" 1841
"	" " . .	44·242	1806·20	0·26034	37 24	220 35	358 38	0·8325	+	Sir J. Herschel
"	" " . .	66·257	1780·124	(28° 0′)	58 3	4 25	194 37	1·1108	+	Villarceau, 1852
"	" " . .	67·309	1779·338	(23° 51′)	59 19	9 52	185 0	1·2015	+	" "
7	Σ 2173 = 221 (B) Ophiuchi . . .	45·43	1872·91	0·1349	80 53	152·65	7 26	1·009	–	Dunér
8	Sirius	49·399	1843·275	0·6148	47 8·7	61 57·8	—	—	–	Auwers
"	"	49·46	1794·262	0·7515	—	—	—	—	–	Mann
"	"	*49·6	A.P=1867·0	0·58	57·1	42·4	—	8·41	–	Colbert
"	"	50·01	1791·431	0·7904	—	—	—	—	–	Peters
9	τ Cygni	53·87	1863·99	0·34 5	44 50	83 0	205 26	1·19	–	Gore, 1886

Binary Stars—continued.

No.	Star	P Years	T	e	γ	Ω	λ	a	μ	Computer
					° ′	° ′	° ′	″		
10	μ^2 Herculis . . .	54 ¼	1877·13	0·3023	60 43	57 57	156 21	1·46	+	Doberck
11	γ Cor. Australis	55·582	1882·774	0·6989	111 27·7	229 9	—	2·400	−	Schiaparelli
"	" " " .	54·985	1883·203	0·6974	69 17	227 23	283 57	2·44	−	Downing, 1883
"	" " " . .	*81·78	1886·53	0·322	47 26	45 25	141 0	1·885	−	Gore, 1885
"	" " " . .	100·80	1863·08	0·602	53 35	352 13	266 25	2·549	−	Jacob, 1858
12	ζ Cancri	58·23	1872·44	0·30230	36 14·4	150 17·4	171 46·8	0·908	−	W. E. Plummer, 1871
"	"	58·2708	1816·687	0·44385	24 0·4	33 34·3	133 0·7	—	−	Mädler, 1848
"	"	58·94	1815·53	(14° 50′)	48 36	18 23	—	1·030	−	Winnecke, 1855
"	"	*59·486	1870·82	0·3318	18 31	358 3	182 33	0·886	−	Doberck
"	"	62·4	1869·3	0·353	20·7	109 0	199·0	0·908	−	O. Struve
13	ξ Ursæ Majoris . .	58·2625	1817·25	0·4164	59 40	95 22	131 38	3·857	−	Savary, 1830
"	" " . .	59·88	1816·405	0·3786	53·1	103·6	135 3	2·591	−	Sir R. S. Ball
"	" " . .	*60·79	1875·29	0·3952	56·9	101·5	234 3	2·549	−	Dunér, 1876
"	" " . .	60·80	1875·26	0·41590	56 40	100 13	235 0	2·580	−	Oxford Obs.
"	" " . .	61·175	1816·66	0·4116	53 52	96 6	129 28	2·82	−	Jacob
"	" " . .	61·30	1817·102	φ=23° 48′·7	50 55·4	96 21·9	132 28·7	—	−	Mädler, 1847
"	" " . .	61·576	1816·86	0·43148	52·82	95 83	128 95	2·439	−	Villarceau
14	O Σ 234	63·45	1881·15	0·3629	47 21	124 11	71 58	0·339	+	Gore, 1886
15	O Σ 298	68·802	1812·96	0·4872	56 10	14 38	342 31	0·886	+	Doberck
"	" "	70·26	1882·22	0·51	50 37·8	12 17·3	346 9·2	0·83	+	Fürst N. Dolgorukow
16	α Centauri . . .	75·3	1858·012	0·966	77 50	177 50	—	30	+	Powell, 1854
"	" . . .	77·0	1851·50	0·950	47 46	86 7	291 22	15·5	+	Jacob, 1848
"	" . .	*77·42	1875·97	0·5260	79 32	25 47	54 47	17·50	+	Elkin
		*76·222	1875·951	0·51578	79 15·2	25 30·5	54 59·2	17·33	+	Downing
"	" . . .	80·94	1859·42	0·7752	62 53	16 42	26 2	13·57	+	Hind, 1851
"	" . . .	82·59	1857·012	0·96887	77 19½	2 35	—	31·7574	+	Powell, 1848
"	" . . .	85·042	1874·85	0·6673	82 18·4	21 48·0	—	21·797	+	Hind, 1877
"	" . . .	87·438	1875·447	0·544326	79 47·1	25 49·6	48 59·3	18·89	+	Powell, 1886
"	" . . .	88·536	1875·12	0·5332	79 24	25 14	45 58	18·45	+	Doberck, 1879
17	70 Ophiuchi . . .	73·76	1806·877	φ = 25° 28′	46 25	147 12	283 3	4·3284	−	Encke
"	" . . .	80·34	1807·06	0·4667	48 5	145 46	292 25	4·392	−	Sir J. Herschel, 1832
"	" . . .	80·61	1806·746	φ = 28° 30′	42 52	133 47	287 14	4·3159	−	Mädler, 1835
"	" . . .	87·52	1807·60	0·4820	51 30	128 33	293 17	4·675	−	Jacob

17	70 Ophiuchi . . .	88·48	1807·48	0·4973	47 20	122 14	294 6	—	−	Hind
"	" . . .	94·37	1808·79	0·49149	57·9	125·4	155·7	4·704	−	Schur, 1868
18	O Σ 235	*94·406	1839·10	0·5870	60 13	96 17	129 55	1·066	−	Doberck
19	γ Cor. Borealis . .	95·50	1843·7	0·387	83	111	239	0·75	−	Doberck
"	" " . .	*95·5	1843·70	0·350	85 12	110 24	233 30	0·70	−	"
20	ξ Scorpii	*95·90	1859·62	0·0768	68 42	12 15	89 16	1·26	+	" 1877
"	"	105·522	1832·611	—	70 13·3	4 52·2	—	1·287	+	Mädler, 1846
21	Σ 3062	*104·415	1834·88	0·4612	32 11	38 35	92 7	1·27	+	Doberck
"	"	112·644	1835·196	0·5009	29·9	32·2	97·5	1·310	+	Schur
"	"	146·83	1834·01	$\phi = 35^\circ\ 7'\cdot5$	38 35·9	77 21·2	42 10·3	0·9982	+	Mädler
22	ω Leonis	82·533	1849·76	0·64338	46 34	135 11	185 27	0·857	+	" 1841
"	"	110·82	1841·81	0·5360	64 5	148 46	121 4	—	+	Doberck, 1876
"	"	*114·55	1841·57	0·5510	64 5	149 15	122 19	0·85	+	"
"	"	117·577	1843·408	0·62564	50 38·2	159 50·5	120 27·5	0·8505	+	Mädler, 1846
"	"	133·35	1876·44	0·3605	57 14	111 51	217 22	0·703	+	Klinkerfues
"	"	142·41	1843·39	0·6286	54 25	162 12	107 9	1·092	+	"
"	"	227·77	1841·40	0·7225	60 13	169 12	84 10	1·307	+	"
23	φ Ursæ Majoris .	115·4	1877·12	0·788	57 57	105 18	72·7	0·54	+	Casey
24	p Eridani . . .	117·51	1817·51	0·378	44 40	81 42	327 15	3·82	−	Doberck
"	"	*224·57	1814·43	0·4127	26 5	48 0	329 52	4·75	−	Downing, 1883
25	25 Can. Venat. . .	124·50	1862·98	0·66	51·5	82·0	202·0	—	−	Doberck, 1877
26	ξ Bootis	117·14	1779·958	0·59374	80 5	359 59	100 59	12·56	−	Sir J. Herschel, 1833
"	"	*127·35	1770·69	0·7081	36 55	26 22	117 46	4·86	−	Doberck
"	"	160·695	1761·71	0·4540	52·7	172·7	315·2	5·591	−	Mädler
27	4 Aquarii	129·84	1751·96	0·4613	56 37	340 14	235 0	0·717	+	Doberck
28	40 (o^2) Eridani (B C)	139·0	1863·88	0·1362	76 20	146 20	354 23	5·99	−	Gore, 1886
29	γ Virginis . . .	141·297	1836·228	0·85661	25 14·1	78 28·4	319 46·1	—	−	Hind, 1845
"	" . . .	143·44	1836·29	0·8590	23 5	70 48	319 23	—	−	Henderson, 1843
"	" . . .	145·453	1836·313	0·86815	24 39	60 38	78 22	3·402	−	Mädler, 1841
"	" . . .	157·562	1836·103	0·86805	35 48	58 23	266 0	3·638	−	" "
"	" . . .	169·445	1836·279	0·88064	25 25	62 9	79 4	—	−	" 1847
"	" . . .	182·12	1836·43	0·87952	23 35·7	5·33	313 45	—	−	Sir J. Herschel
"	" . . .	*185·0	1836·68	0·896	35·1	35·6	283·7	3·97	−	Thiele
30	O Σ 400	170·37	1882·09	0·669	36 58	146 20	43 30	0·59	−	Gore, 1887
31	14 (i) Orionis . .	190·48	1959·05	0·2465	44 57	99 35	302 42	1·22	−	" "
32	τ Ophiuchi . . .	217·87	1818·50	0·6055	46 8	67 1	36 26	1·193	+	Doberck, 1875
33	η Cassiopeiæ . .	*176·37	1924·78	0·6268	68·5	50·8	245·9	10·68	+	Dunér, 1876
"	" . . .	195·235	1901·25	0·6244	48·18	33 20	229·27	8·639	+	Gruber, 1876
"	" . . .	222·435	1909·24	0·5763	53·50	39 57	223 20	9·83	+	Doberck, 1876
34	λ Ophiuchi . . .	95·88	1791·214	0·4772	49 40	30 23	135 24	0·847	+	Hind
"	" . . .	*233·89	1803·91	0·4930	44 44	157 21	94 16	—	+	Doberck
35	44 (i) Bootis . . .	181	1784·7	0·3837	77 36	60 15	12 36	3·10	−	Mädler, 1847
"	" . . .	261·12	1783·01	0·71	70·5	65 29	1 18	3·093	−	Doberck

Binary Stars—continued

No.	Star	P Years	T	e	γ	Ω	λ	a	μ	Computer
					° ′	° ′	° ′	″		
36	μ^2 Bootis	182·6	1866·0	0·491	47 31	166 8	23 1	1·165	−	Winagradkij
36a	Σ 2107	186·207	1893·33	0·3867	45 51·6	186 20·2	104 3·0	1·0	+	Berberich
”	”	98·5	1816·19	0·6688	66 10	139 26	252 12	1·15		Casey
36	μ^2 Bootis	198·93	1865·5	0·4957	46 22	169 0	23 39	—	−	Klinkerfues
”	”	200·4	1865·2	0·51	45 0	172 0	20 5	—	−	Wilson
”	”	*280·29	1860·51	0·5974	39 57	173 42	20 0	1·47	−	Doberck
”	”	290·07	1863·51	0·6174	44 26	182 59	17 41	1·500	−	”
”	”	314·761	1860·88	0·6832	41 52	163 11	54 27	1·761	−	Hind
37	Σ 1819	340·1	1797·0	0·3052	37 31	156 25	348 56	1·46	−	Casey
38	Σ 1757	340·38	1778·81	0·2425	45 51	89 45	203 14	2·25	+	Gore, 1886
”	”	401·0	1797·42	0·5079	29 32	344 43	315 28	2·29	+	Casey
39	36 Andromedæ	349·1	1798·80	0·6537	41 39	57 54	142 19	1·54	+	Doberck
40	γ Leonis	402·62	1741·11	0·7390	43 49	111 50	194 22	2·00	+	” 1876
”	”	*407·04	1741·00	0·7327	43 6	111 34	195 22	1·98	+	” 1879
41	δ Cygni	178·7	1862·86	0·6067	46 23	24 54	243 24	1·811	−	Hind
”	”	280·56	1866·3512	0·8470	64 38·4	166 26·4	—	3·165	−	Behrmann
”	”	*415·11486	1940·1023	0·28583	37 46	91 8	289 42	2·30974	−	”
42	μ Draconis	648·0	1940·35	φ=29° 32′	0 0	—	—	3·38	−	Berberich
43	σ Coronæ	195·12	1831·17	0·309	46 47	1 57	101 57	2·719	+	Jacob
”	”	240·0	1829·7	0·3887	45 6	3 8	96 53	2·94	+	Powell
”	”	286·6	1835·60	0·6112	—	138 0	—	3·679	+	Herschel
”	”	420·24	1825·31	0·5899	40 52·2	20 43·9	65 54·1	2·3851	+	Klinkerfues
”	”	608·45	1826·6	0·69978	29 29	25 7	64 28	3·918	+	Mädler
”	”	736·88	1826·48	0·7256	25 39	21 3	69 24	5·194	+	Hind
”	”	845·86	1826·93	0·7515	31 22	18 21	71 36	5·885	+	Doberck
44	61 Cygni	*782·6	—	0·1736	—	—	—	—	+	Peters
”	” ”	1159	—	0·2484	—	—	—	—	+	Mann
45	Castor	232·124	1913·90	0·79725	70 58	23 5	87 37	7·008	−	Mädler, 1842
”	”	252·66	1855·83	0·75820	70 3	58 6	262 31	8·0861	−	Sir J. Herschel
”	”	519·77	1688·28	0·21938	41 46·7	10 45·6	16 1·7	—	−	Mädler
”	”	632·27	1699·26	0·2405	43 14	11 24	355 41	6·300	−	Hind, 1845
”	”	653·1	1703·30	0·300	43 17	10 0	0 0	6·30	−	Jacob, 1846
”	”	982·9	1742·1	0·38	32 15	28 15	305 10	6·67	−	Wilson, 1877
”	”	996·85	1750·326	0·34382	42 5·4	31 58	294 0·8	7·5375	−	Thiele
”	”	*1001·21	1749·75	0·3292	44 33	27 46	297 13	7·43	−	Doberck
46	ζ Aquarii	*1624·8	1927·74	0·6000	44 50	141 8	134 40	7·64	−	”

In the above list P denotes the period of revolution in years; T the date of periastron passage; e the eccentricity of the orbit; γ the inclination of the real orbit to the plane of projection, or background of the heavens; Ω the position angle of the line of nodes; λ the angle which the line to the periastron makes with the line of nodes in the real orbit; and a is the semi-axis major of the real ellipse measured in seconds of arc.

The position angle and distance of any binary pair at any time, t, may be computed from the elements of the orbit by means of the following formulæ:—

$$(1) \quad u - \mathrm{E} \sin u = \pm \mu (t - \mathrm{T})$$

$$(2) \quad \tan \tfrac{1}{2} \mathrm{V} = \sqrt{\frac{1+e}{1-e}} \tan \tfrac{1}{2} u$$

$$(3) \quad \tan (\theta_c - \Omega) = \cos \gamma \tan (\mathrm{V} + \lambda)$$

$$(4) \quad \rho = a (1 - e \cos u) \frac{\cos (\mathrm{V} + \lambda)}{\cos (\theta_c - \Omega)}.$$

Where E is the eccentricity expressed in degrees $= 57^\circ{\cdot}296 \times e$; μ is the mean annual motion $= \frac{360}{\mathrm{P}}$, the + sign being used when the apparent motion of the companion round the primary star is in the direction of *in*creasing position angles, and the − sign when the position angle is *de*creasing; u is the eccentric anomaly, and V the true anomaly for the epoch t; θ_c the required position angle, and ρ the distance.

In some of the elements in the table the 'angle of eccentricity,' ϕ, is given. The sine of this angle is e, or $\phi = \sin^{-1} e$.

Notes on the Binary Stars in the Preceding List.

1. ζ *Sagittarii.* A double star discovered by Winlock. Burnham's measures 1878–1881 prove that the pair is certainly binary. Although founded on only a small number of measures, the period found by Gore is probably not far from the truth.

2. 42 *Comæ Berenices.* In 1874 O. Struve remarked with reference to this star, 'During the last forty years [it] has presented three times more the rare phenomenon of an occultation of one star by another.'

3. *β Delphini.* One of Burnham's discoveries. Both sets of elements represent the recorded measures fairly well.

4. *ζ Herculis.* Doberck's elements are probably the most correct.

5. Σ 3121. None of the orbits given are satisfactory. Some of the measures are very discordant. Fritsche's orbits are based on the observations of the two Struves.

6. *η Coronæ Borealis.* Doberck's elements are probably the best.

7. Σ 2173. Dunér's elements represent the observations fairly well.

8. *Sirius.* Colbert's orbit is probably the most correct. It represents the observations up to 1885 very satisfactorily. The date given in column T is the epoch of *apoastron* passage.

9. *τ Cygni.* Recent measures made with the large American refractors render the correctness of the elements given very doubtful. These measures, however, are very discordant.

11. *γ Coronæ Australis.* Gore's elements represent recent measures much more closely than the orbit found by Schiaparelli (and corrected by Downing). Schiaparelli's period is certainly too short.

12. *ζ Cancri.* A remarkable ternary system, but the period of revolution of the third star (5·5 m.: 130·4: 5·38: 1875·25, Schiaparelli) round the binary pair is very long, probably 600 to 700 years. The third star has described several loops in its apparent orbit since 1827, and we have here an example of the problem of three bodies mutually disturbing each other's motions, and for which mathematical 'analysis does not yet furnish the means of solution.'

13. *ξ Ursæ Majoris.* Remarkable as being the first binary star for which an orbit was computed—by Savary in 1830. There is not much difference between the various sets of elements found by different computers.

14. O Σ 234. The recorded measures of this very close and difficult double star are very discordant, and the correctness of the resulting elements is consequently doubtful.

15. O Σ 298. The two sets of elements given are in tolerably close agreement, but do not represent recent measures well.

16. *α Centauri.* From recent researches on the orbit of this remarkable binary, Powell thinks that the period is probably 86 or 87 years (*Mon. Notices*, R.A.S., November 1884). Downing, however, can 'see no evidence that a period differing much from 76·222 years is required to satisfy the observations' (*Mon. Notices*, R.A.S., January 1885).

17. 70 *Ophiuchi.* According to Sadler none of the orbits calculated for this system are satisfactory. Herr Schur is at present collecting materials for a correction of the elements calculated by him; but as the stars are again approaching their periastron, and are now moving rapidly, some years must elapse before a satisfactory revision of the orbit can be made. Jacob suspected disturbance from a third invisible companion. Krüger found a parallax of 0″·162.

19. *γ Coronæ Borealis.* Doberck's first elements are founded on Struve's observations. 'The plane of the apparent orbit of this star, like that of 42 Comæ Ber., approximately coincides with the visual ray.'

20. *ξ Scorpii.* The real orbit is nearly circular. The apparent orbit, owing to the high inclination, is very elongated. A whole revolution has been completed since it was measured by Sir W. Herschel in 1782.

21. Σ 3062. Doberck's elements are probably the best. It has a proper motion of + 0″·346 in R.A. and − 0″·020 in N.P.D.

22. *ω Leonis.* Doberck's elements are the best.

24. *p Eridani.* Measures by Tebbutt, 1880–85, show that Downing's elements represent the position angles well, but not the distances. An orbit has recently been computed by Gore.

26. *ξ Bootis.* Doberck's elements are probably the best.

28. 40 (o^2) *Eridani.* Doberck thinks that the orbit is very eccentric and not circular. Gore's elements represent the measured angles 1783–1883 tolerably well, but the distances not so well. The elliptical motion is probably somewhat perturbed by the attraction of the principal star, which, though very distant (about 81″), is probably much larger, its apparent magnitude being about 4½, while the components of the binary pair are about 9 and 11. All three stars have a large common proper motion of about 4″·07 per annum in the direction of position angle

212°·4. Professor Asaph Hall found a parallax of 0″·223. This, combined with the elements, gives a combined mass for the binary pair of 1·003 times the mass of the Sun.

29. γ *Virginis.* None of the orbits of this famous binary are quite satisfactory. Thiele's elements satisfy the observed angles between 1864 and 1875, but not the distances. A variation in the relative light of the components has long been suspected.

30. O Σ 400. A difficult double star even with large telescopes.

31. 14 (*i*) *Orionis.* Some of the recorded measures in recent years are very discordant, but some measures early in 1887, by Mr. Tarrant in England and Professor C. A. Young (Princeton) in America, are in close agreement.

32. τ *Ophiuchi.* Doberck's elements represent the measures from 1783 to 1871 very satisfactorily.

33. η *Cassiopeiæ.* Sadler thinks that Dunér's value of *a* 'is much too large,' and that it probably does not exceed 8″·5. O. Struve found a parallax of 0″·154 for this star.

35. 44 (*i*) *Bootis.* This system has a proper motion of −0″·045 in R.A. and −0″·03 in N.P.D.

38. Σ 1757. Both sets of elements represent the observations from 1825 to 1883 tolerably well, but as only a small arc of the apparent orbit (about 60°) has been described since its discovery, the elements will doubtless require correction hereafter.

41. δ *Cygni.* Behrmann's second elements (period, 415·11486 years) are the best, but still not quite satisfactory. Owing to the great inequality in the light of the components, the star is a difficult object to measure, except on nights of first-rate definition.

43. σ *Coronæ.* Doberck's elements are probably the best. They represent the observations from 1781 to 1876 very closely.

44. 61 *Cygni.* Peter's elements represent the observations, from the earliest times down to 1883, with considerable accuracy.

45. *Castor.* Sadler thinks that 'a good orbit for Castor has yet to be computed.'

J. E. G.

Position, Magnitudes, &c., of the Binary Stars in the Preceding List.

No.	Star	R.A. 1880·0	Decl. 1880·0	Mags.	Remarks
		h. m. s.	° ′		
1	ζ Sagittarii . . .	18 55 0	−30 3	3½, 4	
2	42 Comæ Beren. .	13 4 10	+18 10	6, 6	
3	β Delphini	20 31 55	+14 11	3·5, 4·5	
4	ζ Herculis	16 36 47	+31 49	3, 6·5	Colours yellowish, reddish
5	Σ 3121	9 10 46	+29 7	7·5, 7·8	
6	η Cor. Borealis . .	15 18 14	+30 43	5·8, 6·2	White, golden yellow
7	Σ 2173	17 24 14	− 0 58	6·0, 6·0	
8	Sirius	6 39 53	−16 33	1, 10	
9	τ Cygni	21 10 0	+37 32	5·6, 7·9	Colours yellow, blue
10	μ^2 Herculis . . .	17 41 47	+27 48	9·5, 10·5	
11	γ Coronæ Australis .	18 59 0	−37 18	6, 6	
12	ζ Cancri	8 5 20	+18 1	5, 5·7	
13	ξ Ursæ Majoris . .	11 11 48	+32 13	4, 5	'Subdued white, greyish white'
14	O. Σ 234	11 24 18	+41 58	7, 7·4	
15	O. Σ 298	15 31 42	+40 13	7, 7·3	
16	α Centauri	14 31 48	−60 20	1, 2	
17	70 Ophiuchi . . .	17 59 23	+ 2 33	4·1, 6·1	Both yellow, Franks, 1876
18	O. Σ 235	11 23 48	+61 45	6, 7·3	Colours yellow, red
19	γ Cor. Borealis . .	15 37 42	+26 41	4, 7	
20	ξ Scorpii	15 57 46	−11 3	4·9, 5·2	Variation in relative mag. suspected
21	Σ 3062	23 59 57	+57 46	6·9, 8	
22	ω Leonis	9 22 2	+ 9 35	6·2, 7	Yellow, yellower
23	φ Ursæ Majoris . .	9 44 0	+54 37	5, 5·6	
24	p Eridani	1 35 12	−56 49	6, 6	
25	25 Can. Venat. . .	13 32 0	+36 54	5, 7·6	Colours white, blue
26	ξ Bootis	14 45 48	+19 36	4·7, 6·6	Yellow, orange (Dembowski)
27	4 Aquarii	20 45 6	− 6 4	5·9, 7·2	
28	40 (o²) Eridani (BC)	4 9 52	− 7 47	9, 11	
		h. m.			
29	γ Virginis	12 35·6	− 0 47	3, 3	Components suspected of variable brightness
30	O. Σ 400.	20 6·2	+43 37	7·2, 8·2	
31	14 (ι) Orionis . . .	5 1·3	+ 8 20	6, 6·8	
32	τ Ophiuchi . . .	17 56·5	− 8 11	5, 5·7	Pale white
33	η Cassiopeiæ . . .	0 41·8	+57 11	4, 7·6	Yellow, purple
34	λ Ophiuchi . . .	16 24·9	+ 2 15	4, 6·1	Yellow, bluish
35	44 (ι) Bootis . . .	14 59·8	+48 7	5·2, 6·1	Variable light suspected
36	μ^1 Bootis	15 20	+37 46	6·7, 7·3	
36a	Σ 2107	16 47·1	+28 52	6·5, 8	Yellowish, bluish
37	Σ 1819	14 9·3	+ 3 41	7·9, 8	
38	Σ 1757	13 28·2	+ 0 18	7·8, 8·9	
39	36 Andromedæ . .	0 48	+22 58	6·2, 6·9	Variable mag. according to Schmidt
40	γ Leonis	10 13·4	+20 27	2, 3·5	
41	δ Cygni	19 41·2	+44 50	3, 7·9	Companion sus. variable
42	μ Draconis. . . .	17 2·9	+54 38	5, 5·1	White, pale white
43	σ Coronæ	16 10·9	+34 10	8·6, 9·1	Both white
44	61 Cygni	21 1·4	+38 7	5·3, 5·9	'Yellow, deeper yellow'
45	Castor	7 27	+32 1	3. 3·5	Bright white, pale white
46	ζ Aquarii	22 22·6	− 0 38	4, 4·1	'Flushed white, creamy'

CHAPTER VIII.

VARIABLE STARS.

[THE stars whose light undergoes a periodical fluctuation in intensity, of greater or less degree, are called variables, and the study of their variation, with a view to the exact determination of its period and degree, presents an interesting and useful field of work. The known variables number over two hundred. Of many of these more precise determinations of the dates of maxima are wanted. The stars *suspected* to be variable are very numerous, and in the case of these the object of further observation is to place them beyond suspicion by fixing the particulars of their variability. A search for new suspected variables on the part of amateurs is hardly to be encouraged. It is extremely easy for a fresh and comparatively unpractised observer to fancy that he has detected traces of variation; and if he announce his discovery, and the object be included amongst the suspected variables, much valuable time may be lost by many workers in establishing a negative and profitless result. Mr. Gore's catalogue[1] contains particulars of no fewer than 736 objects, in the reduction

[1] *A Catalogue of Suspected Variable Stars.* With Notes and Observations. By J. E. Gore, M.R.I.A., F.R.A.S. (Reprint from the *Proceedings of the Royal Irish Academy.*) Dublin, University Press, 1885.

of which a number of observers have abundant work for a long time to come.

EQUIPMENT.—To a considerable extent this branch of work can be followed with small optical means. Many variables may be well observed at their maximun brilliancy with the naked eye. Some merely require the aid of a good opera-glass to watch them through all their changes. Others, again, at their period of minimum light, are invisible except in a fairly powerful telescope. As, however, instrumental aid should be employed as sparingly as possible—a glass never being used when the naked eye will do, or a large telescope when a small one will serve—this research may be regarded as essentially non-telescopic.

It is assumed that the observer will rely on the old and, in the meantime, more reliable method of determining magnitudes by the unassisted eye. In the hands of Professor Pritchard, the 'wedge photometer' has yielded good results, but what it would give in the hands of amateurs is another matter. Dr. Lindemann, of Pulkova, has found that Zoellner's photometer is unreliable in dealing with red stars to the extent of about one magnitude, and, as most variables are of a ruddy tint, the instrument is practically disqualified for use in such work. For the present, the observer who is sufficiently painstaking will probably attain the most satisfactory results by following in the footsteps of Dr. Gould, and endeavouring to train his eye to exactitude in light comparisons.

ORGANISATION OF OBSERVERS.[1]—Harvard College Observatory has for some years prosecuted systematic work in the study of variable stars, and the director, Professor E. C. Pickering, has published a pamphlet setting forth a plan for securing co-operation amongst observers. The

[1] See also p. 13.

advantages of co-operation in astronomical work have already been dwelt upon, so we need do no more here than advise those who intend to take up the interesting study of variables to communicate with Professor Pickering.]

METHOD OF COMPARISON.—The best method of observing variable stars, with a view to determining the dates of maxima and minima, is that known as Argelander's. This method consists in estimating with the naked eye, or an opera-glass (or telescope if necessary), the difference in 'steps' or 'grades' between the variable, or suspected variable, and a companion star not differing much from it in brilliancy. A 'step' is usually supposed to be about $\frac{1}{10}$th of a magnitude. This differs with different observers, but has generally a fixed, or nearly fixed, value for each individual. This value may be found by the observation of a number of stars whose magnitudes have been determined by photometric measurement or otherwise. If, however, we compare the star under examination with one star slightly brighter, and another slightly fainter, the magnitudes of the comparison stars being known, the absolute value of the observer's step will be of no consequence. Differences of more than four steps should, if possible, be avoided, as larger differences cannot be estimated with any degree of certainty.

COMPARISON STARS.—For the brighter variables, comparison stars [1] may be selected either from Professor Pritchard's measures (vol. xlvii. of the 'Memoirs of the Royal Astronomical Society') or from the Harvard Photometry recently published. For the fainter variables, comparison

[1] A list of stars brighter than the fourth magnitude, for comparison with the brighter variables, is appended to this chapter (p. 247).

stars may be obtained from Argelander's *Durchmusterung* or from Dr. Gould's *Uranometria Argentina*, in which a list of standard stars near the equator is given. With a good opera-glass observations of stars down to $7\frac{1}{2}$ or 8th magnitude may be easily made.

To enable the observer to identify the variable or suspected variable, a chart of the vicinity should be drawn in a large note-book, and a list of comparison stars with their magnitudes added. These charts may be copied from either the *Durchmusterung* charts or Harding's Atlas. The latter will be found very useful for the identification of stars down to the 9th magnitude, as it is on a good-sized scale (about 2° to the inch), and the magnitudes are very clearly shown. The epoch of Harding's Atlas (1800) is the same as that of Lalande's large catalogue, which makes it easy to identify comparison stars, especially those included in the 'Uranometria Argentina,' where the number of the star in Lalande's catalogue is generally quoted.

By selecting a number of comparison stars near the variable or suspected variable, differing only a little from it in brilliancy, but forming a sequence of magnitudes, a very accurate estimate may be made of the relative brightness of any star whose magnitude it is wished to determine. For instance, if we are observing a star variable, or supposed to be variable, from say 4 m. to 6 m., the following comparison stars might, if available in the vicinity, be selected: 3·8 m., 4·0, 4·2, 4·4, 4·6, 4·8, 5·0, 5·2, 5·4, 5·6, 5·8, 6·0, and 6·2 m., or as near these magnitudes as possible. With these comparison stars there would be no difficulty in estimating the star's light at any time to within a tenth of a magnitude. So good a sequence of comparison stars cannot, of course, always be obtained sufficiently near the variable, and in such cases we must only select

the most suitable stars available in the vicinity. If a considerable difference of brightness exists between the comparison stars, the magnitude of the variable may be determined very approximately by the following method: Suppose the magnitude of the star lies between two stars whose magnitudes are known to be 5·4 and 6·2. Then, by estimating to which of the stars it approaches nearer in brilliancy, a very accurate estimation may be arrived at. Thus if estimated to be exactly midway in light between the two comparison stars, its magnitude would evidently be $\frac{1}{2}(5{\cdot}4 + 6{\cdot}2)$ or 5·8. If, however, slightly nearer to the brighter in lustre, it would be 5·7, and if slightly nearer to the fainter, it would be 5·9. If considerably nearer to the brighter, we might put it down as 5·6, or, if much nearer to the fainter, as 6·0.

In making these estimations of magnitudes, a comparison star should be taken, having, if possible (at the time of observation), about the same altitude above the horizon as the star whose magnitude is to be estimated. Professor Pickering states that 'two stars apparently equal show a difference when placed one above the other.'

Method of Observation.—When comparing the relative brightness of two stars near each other, no attempt should be made to observe both the stars simultaneously. Each should be looked at directly, and the eye passed rapidly from one to the other a number of times, so that the light of each star may fall upon the same portion of the retina. This is very necessary, as it will be found by the observer that a star seen by averted vision usually looks brighter than when looked at directly, probably because its light falls on a more sensitive portion of the retina. Only very clear nights should be employed for making these observations, and care should be taken that none of the

comparison stars are dimmed by small fleecy clouds, which often occur in an otherwise clear sky.

Some observers, in estimating star-magnitudes by the method above described, put the opera-glass or telescope slightly out of focus, and consider that in this way the effect of a star's colour on the eye is to a great extent eliminated. With reference to this method, however, Dr. Gould says ('Uranometria Argentina,' p. 252, note to *l* Carinæ): 'The results are not very satisfactory, owing in part to the circumstance that many of the comparisons were made by putting the opera-glass out of focus, a method which our experience shows not to give results in accordance with estimates by the method of sequences, or by comparisons with artificial stars of measurable brilliancy.'

For the brighter stars Heis's Atlas, Argelander's 'Uranometria Nova,' or Proctor's Atlas may be used, and for southern stars the 'Uranometria Argentina.'

MAGNITUDE.—In connection with the subject of variable stars and star-magnitudes it may be asked, what is the exact meaning of a difference of one magnitude between the light of two stars? The answer to this is that the 'light ratio' now almost universally adopted by astronomers is 2·512—that is, 'the ratio of the intensities of light which shall define the meaning of "difference of a single magnitude" between the light of two stars.' Thus if L_m represents the light of a star of magnitude m; L_{m+1} the light of a star one magnitude fainter; L_{m+2} that of a star two magnitudes fainter, and so on, then

$$L_m = 2{\cdot}512\ L_{m+1}$$

$$L_{m+1} = 2{\cdot}512\ L_{m+2}, \text{ and so on.}$$

$$\therefore\ L_m = (2{\cdot}512)^2\ L_{m+2} = (2{\cdot}512)^3\ L_{m+3},$$

$$\text{or generally } L_m = (2{\cdot}512)^n\ L_{m+n};$$

or, as logarithm of $2{\cdot}512 = 0{\cdot}4$ nearly,

$$\log L_m = 0{\cdot}4\ n + \log L_{m+n}.$$

Suppose $m = 1$ and $n = 2$,

$$\text{then } L_1 = (2{\cdot}512)^2 L_3 = 6{\cdot}310144\ L_3$$

—that is, the light of a star of 1st magnitude is 6·31 times the light of a star of 3rd magnitude, or generally the light of any star is 6·31 times the light of a star two magnitudes fainter. Hence in the case of a star which is variable to the extent of two magnitudes, its light at maximum is more than six times its light at minimum. This is a considerable difference, and shows that the light of the star is subject to great changes. Some of the known variables fluctuate much more than this. For instance, R Hydræ 6 magnitudes, U ('Nova') Orionis about 6½, Mira Ceti about 7 magnitudes, and χ Cygni about 8 magnitudes! This shows an enormous change in light of the star. In the case of χ Cygni, its light at maximum is about 1,600 times its light at minimum (!) Such a change in a star's light is very wonderful and interesting.

Correction for Variables of the Algol Type.—In the case of variable stars of long period it will in general only be possible to determine the epoch of maximum or minimum to a day or fraction of a day. With the short period variables, such as δ Cephei, β Lyræ, the time may usually be found within a few minutes. In the case of variables of the Algol type, where, owing to the rapidity of the light change, the time of minimum may generally be determined within a fraction of a minute, it will be necessary to make a correction to the time of observation due to the progressive motion of light, so as to reduce the time to that of a fixed point, such as the centre of the Sun. The necessity for this correction will be evident if we consider a minimum

to take place when the star is nearly in opposition to the Sun. Its light will then reach us about eight minutes *sooner* than it would arrive at the Sun's centre. On the contrary, supposing the star to be nearly in conjunction with the Sun, its light would then reach us about eight minutes later than the centre of the Sun, this being the time occupied by light in passing from the Earth to the Sun. There would thus arise an error of over 16 minutes between the two observations. In intermediate positions of the star, the necessary correction—known as the 'equation of light'—may be calculated in the following manner. Knowing the right ascension and north polar distance of the star, and also of the Sun at the moment of observation, we can, having two sides (the polar distances) of a spherical triangle, and the included angle (equal to the difference of the right ascensions), calculate the third side, or the angular distance between the Sun and star. Then the natural cosine of the supplement of this angle, multiplied by the time taken by light in passing between the Earth and Sun (about 8·3 minutes), will give the necessary correction, to be added to the observed time if the cosine is positive (i.e. when the supplement is less than 90°), and subtracted if the cosine is negative. The result will give the heliocentric time of the observed minimum.

To take an example. The remarkable variable U Ophiuchi (No. 52 of following list), discovered to be a variable of the Algol type by Mr. Edwin F. Sawyer in 1881, has the shortest period known, viz. $20^h\ 7^m\ 41^s{\cdot}6$. A minimum of this star was observed by Sawyer on June 17, 1884, at $9^h\ 37^m{\cdot}2$. Cambridge (U.S.A.) mean time. It is required to find the correction due to the equation of light. Reducing the place of the star to the epoch of observation in the usual way, we find the position for June 17,

1884, R.A. $17^h\ 10^m\ 40^s$, N.P.D. 88° 39′ 39″. The Sun's place at this time was $5^h\ 47^m\ 47^s$ and N.P.D. 66° 35′. Difference of right ascensions of Sun and star is $11^h\ 22^m\ 53^s$ = 170° 43′.

$$\begin{aligned} \text{Now let } P &= \text{diff. of R.A.} &&= 170^\circ\ 43' \\ C &= \text{N.P.D. of sun} &&= 66^\circ\ 35' \\ C' &= \text{N.P.D. of star} &&= 88^\circ\ 39'\ 39'' \\ \text{and } D &= \text{required angular distance.} \end{aligned}$$

Then proceeding by the rules of spherical trigonometry we have

$$\text{Radius} : \cos P :: \tan C : \tan \theta$$

$$\therefore \tan \theta = \frac{\cos P.\ \tan C}{\text{Rad}}$$

$$\begin{aligned} \log \cos P = \log (180^\circ - 170^\circ 43') &= 9{\cdot}9942743 \\ \log \tan C = \log \tan 66^\circ\ 35' &= \underline{10{\cdot}3634278} \\ &\ 20{\cdot}3577021 \\ &\ \underline{10{\cdot}} \\ \log \tan \theta &= 10{\cdot}3577021 \end{aligned}$$

$$\therefore \theta = 66^\circ\ 18'\ 24''.$$

Again—

$$\text{Cos } \theta : \cos (C' - \theta) :: \cos C : \cos D$$

$$\therefore \cos D = \frac{\cos (C' - \theta) \cos C}{\cos \theta}$$

$$\begin{aligned} \log \cos (C' - \theta) &= \log \cos 22^\circ\ 21'\ 15'' &&= 9{\cdot}9660716 \\ \log \cos C &= \log \cos 66^\circ\ 35' &&= \underline{9{\cdot}5995357} \\ & &&\ 19{\cdot}5656073 \\ \log \cos \theta &= \log \cos 66^\circ\ 18'\ 24'' &&= \underline{9{\cdot}6040544} \\ & &&\log \cos D = 9{\cdot}9615529 \end{aligned}$$

$$\therefore D = 156^\circ\ 14'\ 43''.$$

Then supplement = 180° − 156° 14′ 43″ = 23° 45′ 17″ and natural cosine of 23° 45′ 17″ = 0·9152783.

Then $0{\cdot}9152783 \times 8{\cdot}3 = 7{\cdot}596$ minutes, the required correction.

As the supplement is less than 90°, this correction must be *added* to the observed time of minimum.

Hence we obtain,

$$\text{Heliocentric time of minimum} = 9^{h.}\ 37^{m.}{\cdot}2 + 7{\cdot}596$$
$$= 9^{h.}\ 44^{m.}{\cdot}796.$$

At present there are only eight stars of the Algol type known. These are: U Cephei, Algol, λ Tauri, S Cancri, δ Libræ, U Coronæ, U Ophiuchi, and a star in Cygnus (discovered by Chandler in 1886). Of these, S Cancri varies from 8·2 to 9·8–11·7 m. with a period of $9^d\ 11^h\ 37^m{\cdot}75$ (position for 1880, R.A. $8^h\ 37^m\ 5^s$, N. 19° 27′ 57″), and U Coronæ (R.A. $15^h\ 13^m\ 18^s$, N. 32° 5′ 18″) from 7·6 to 8·8 m. in a period of $3^d\ 10^h\ 51^m\ 14^s{\cdot}6$. Details of the others will be found in the appended list.

Determination of Magnitude.—The magnitude of a variable star at minimum may be determined by the method of limiting apertures. If M be the magnitude required, and m the magnitude just visible with one-inch aperture, and if A be the aperture with which the star under examination is *just* visible on a clear moonless night, then $M = m + 5 \log A$. This formula is due to Pogson, who found that, *for his own sight*, $m = 9{\cdot}2$ magnitude in Argelander's scale.

Temporary Stars.—Among the variable stars may be included the so-called 'temporary' stars. These are stars which have suddenly blazed out in the heavens, and, remaining visible for a few weeks or months, have disappeared or become invisible to the naked eye. The appearance of a good many of these stars has been recorded in history. The most remarkable, perhaps, was that observed by Tycho Brahé in November 1572. He has left on record

a very elaborate account of his observations of this wonderful object, known as the 'Pilgrim' star—his description covering no less than 478 pages of printed matter, perhaps the most remarkable astronomical monograph ever published. When at its brightest, the star rivalled Venus in brilliancy, and was visible in the daytime! It gradually diminished, however, and in March 1574 had entirely disappeared. Argelander found a small star, about 11 m., close to the calculated place of Tycho's star. This star has also been observed by Espin. The position of Tycho's star for 1880 is R.A. $0^h\ 18^m\ 9^s$, N. 63° 28′ 51″.

A remarkable star was discovered in October 1604 in Ophiuchus by Brunowski, one of Kepler's pupils. When first seen it was brighter than Mars or Jupiter, but gradually diminished, and in March 1606 had disappeared. Its position for 1880 is $17^h\ 23^m\ 27^s$, S. 21° 22′ 42″.

A star of the third magnitude was observed in Vulpeculæ in 1670. Position for 1880 is $19^h\ 42^m\ 45^s$, N. 27° 1′ 28″. There is a small star near the place.

A new star of $4\frac{1}{2}$ magnitude was discovered in Ophiuchus by Mr. Hind in 1848. Position for 1880, $16^h\ 52^m\ 48^s$, S. 12° 42′ 30″. This star is still visible, but very faint.

A very remarkable star of the second magnitude was discovered in May 1886 in Corona Borealis by Birmingham. It was found that this star had been previously registered by Argelander as $9\frac{1}{2}$ m., and it is still visible as a small star. It place for 1880 is $15^h\ 54^m\ 29^s$, N. 26° 15′ 36″.

A similar star was discovered in November 1876 in Cygnus by Professor Schmidt. When first seen it was 3 m.; but steadily diminished, and it was estimated about 15 m. by Lohse in 1885. Its position for 1880 is $21^h\ 37^m\ 0^s$, N. 42° 17′ 44″. Both this star and the star of 1866 showed bright lines in the spectroscope.

A later instance of this kind is that of a small star which appeared in August 1885 close to the nucleus of the great nebula in Andromeda (31 Messier). It seems to have been first noticed by Mr. Isaac W. Ward, of Belfast, on August 19 at 11 P.M. It was afterwards seen independently by M. Lajoye on August 30, by Dr. Hartwig at Dorpat on August 31, and by Mr. G. T. Davis at Theale, near Reading, on September 1. Its spectrum was found to be similar to that of the nebula itself, viz. continuous without lines, but deficient at the red end. Afterwards, however, Dr. Huggins found some bright lines between D and *d* in its spectrum, 'a continuous spectrum being visible from D to F.' From the similarity of the spectrum with that of the nebula, Proctor concludes that the star and nebula are physically connected, but Dr. Copeland holds the opinion that the star was not new, but merely the temporary brightening of an old star.

A reddish star of the sixth magnitude was discovered by Mr. J. E. Gore near χ^1 Orionis on the evening of December 13, 1885. This star, previously unknown to astronomers, was at first thought to be a 'temporary star,' but subsequent observations have shown that it is an ordinary long-period variable, with a period of about a year. At minimum it descends to about $12\frac{1}{2}$ magnitude. Its spectrum is a splendid one of Secchi's third type.

CLASSIFICATION.—The following classification of variables has been proposed by Professor Pickering, of Harvard College (U.S.A.), and is that adopted in a paper by Mr. Gore in the *Journal* of the Liverpool Astronomical Society (vol. v. part i., November 1886).

Class I.—Temporary stars. Examples: Tycho Brahé's star of 1572, in Cassiopeia, Nova Cygni, 1876. All the stars in

this class, with the single exception of T Coronæ (Nova 1866), lie in or near the Milky Way.

Class II.—Stars undergoing considerable variations of brightness in periods of several months, or years. Examples: Mira (o) Ceti, χ Cygni, η Argûs.

Class III.—Irregularly variable stars undergoing, as a rule, but slight changes of brightness, the laws of which are unknown. Examples: α Orionis, ϵ Aurigæ, μ Cephei.

Class IV.—Short-period variables, in which the light is continually varying with great regularity in a period not exceeding a few days. Increase of light generally quicker than decrease. Examples: δ Cephei, β Lyræ, η Aquilæ, S (10) Sagittæ. All the stars in this class, with one exception (W. Virginis, period 17·27 days), lie in or near the Milky Way, and only one (W Virginis) is noted as reddish.

Class V.—Remarkable diminution of light for a few hours every few days, this phenomenon recurring with great regularity. Examples: Algol (β Persei), U Ophiuchi. There are only eight known members of this class. The general colour is white, or only slightly yellow. Chandler finds that the shorter the period of the star the higher is the ratio which the time of light variation bears to the whole period.

J. E. G.

APPENDIX I.

KNOWN VARIABLE STARS.

The following list is confined to objects particularly easy of observation, at least at the period of maximum light, when most of them can be well observed with a good opera-glass, and some even with the naked eye. Careful determinations of the dates of maxima will be valuable in the investigation of their light changes. They are given in order of right ascension, the positions being for the epoch 1880·0.

1. *Lalande*, 405 *Ceti*. $0^h\ 15^m\ 42^s$, S. $20°\ 43'·4$. Max. 5·2 m.; min. 7 m. A variable of the type of R Scuti, discovered by Chandler (U.S.A.) in 1882.

2. *T Cassiopeiæ.* $0^h\ 16^m\ 45^s$, N. 55° 7′·5. Max. 6·5–7·8; min. 11 m. Mean period, 436 days. A maximum occurred Oct. 16, 1885. It has a spectrum of Secchi's third type. (See chapter on Stellar Spectra.)

3. *R Andromedæ.* $0^h\ 17^m\ 44^s$, N 37° 54′·6. Max. 5·6–8·6 m.; min. about 13 m. Mean period, 404·7 days. Maxima were observed by Schmidt 1882, Oct. 28 (6·7 m.), and 1883, Dec. 15 (7 m.) and by Sawyer 1883, Dec. 1 (6·9 m.); 1884, Dec. 1 (6·9 m.), and 1885, Jan. 10 (6·6 m.). It has a remarkable spectrum of the third type, but with irregularities in the relative intensity of the bands (Dunér).

4. *U Cephei.* $0^h\ 52^m\ 35^s$, N. 81° 13′·8. A remarkable variable of the type of Algol, discovered by M. Ceraski in 1880. Max. mag. 7·2; min. 9·1–9·4. All the light changes take place in a period of about six hours. Period, 2·492886 days, according to Schmidt. As two periods are nearly equal to five days, the alternate minima are observable at nearly the same hour in the evening. As in the case of Algol, Prof. Pickering considers that the variation of light is probably caused by an eclipsing satellite, and that in this case the eclipse is possibly a total one, the light at minimum being that emitted by the satellite, which is self-luminous; or the obscuring body may be supposed to consist of a cloud of meteors so scattered that about 0·11 of the light of the star can pass through them.

5. *S Cassiopeiæ.* $1^h\ 10^m\ 52^s$, N. 71° 58′·8. Max. 6·7–8·5; min. below 13. Mean period, 615 days. Schönfeld finds the increase of light considerably quicker than the decrease. A maximum occurred on May 8, 1868.

6. *R Sculptoris.* $1^h\ 21^m\ 27^s$, S. 33° 10′·4. Varies from 5·75 to 7·75 m. in a period of about 207 days, but somewhat uncertain. A minimum occurred on Nov. 15, 1878. It is a very red star.

7. o (*Mira*) *Ceti.* $2^h\ 13^m\ 18^s$, S. 3° 31′·3. A very remarkable and interesting variable, and well deserving the name *Mira*, or Wonderful. At the maximum the magnitude varies from 1·7 to 5 at different maxima. At minimum the star is about 9 m. The mean period is about 331⅓ days, but is subject to irregularities. The star has a remarkable spectrum of the third type, described by Dunér as 'tout à fait incomparable,' and in which

bright lines have been seen by Secchi. Maxima were observed by Schmidt on June 20, 1882; by Sawyer 1885, Feb. 10, and by Gore 1885, Feb. 4. Schmidt observed a minimum 1883, Nov. 28, and says, 'Helle sehr wenig geringer als die des Nachbarsternes.' During the next few years, Mira will be well situated for observation at the time of maximum light.

8. *β Persei* (*Algol*). $3^h\ 0^m\ 22^s$, N. 40° 29′·6. Max. 2·2; min. 3·7 m. Period, 2·86727 days. The light is constant at the maximum brightness for the greater portion of the period. It then begins to decrease, and all the light changes take place in a period of about 10 hours. Professor Pickering believes that the decrease in the light of this star is due to a dark eclipsing satellite, revolving round the primary in a circular orbit. The Persian astronomer Al Sufi, in his 'Description of the Heavens,' written in the tenth century, describes it distinctly as a red star. It is now white, and this is perhaps the best attested instance on record of change of colour in a bright star.

9. *λ Tauri*. $3^h\ 54^m\ 1^s$, N. 12° 8′·9. A variable of the Algol type. Max. 3·4 m.; min. 4·2 m. Period, 3·952 days. The greater part of the light change is accomplished in a period of 10 hours.

10. *R. Aurigæ*. $5^h\ 7^m\ 37^s$, N. 53° 27′. Max. 6·5–7·8; min. 12·7 m. Mean period, 465 days. A maximum was observed by Schmidt 1883, Jan. 30, mag. 7·8; increase of light quicker than the decrease.

11. *α Orionis*. $5^h\ 48^m\ 40^s$, N. 7° 23′·4. This bright reddish star is, according to Sir J. Herschel, subject to a small fluctuation of light to the extent of about 0·4 mag. Argelander found a period of 196 days, but later observations render this result doubtful. It has a splendid spectrum of the third type.

12. *U* ('*Nova*') *Orionis*. $5^h\ 48^m\ 41^s$, N. 20° 9′·3. Max. 5·9–6·3; min. below 12 m. Period about 360 days. Discovered by Gore as a 'new star,' Dec. 13, 1885. Reddish. The spectrum is a very remarkable one of the third type.

13. *η Geminorum*. $6^h\ 7^m\ 38^s$, N. 22° 32′·5. Max. 3·2; min. 3·7–4·2 m. In 1882 Schmidt found that the increase of light was much quicker than the decrease, and from his observations in 1883 he found from the maximum a period of 151 days, and from the minimum 135 days. Sawyer found the light nearly

constant from Nov. 20, 1884, to Feb. 3, 1885. Spectrum of the third type.

14. T *Monocerotis.* $6^h\ 18^m\ 48^s$, N. 7° 9′·0. Max. 6·2; min. 7·6 m. Period, 26·76 days. An interesting variable.

15. *S* (15) *Monocerotis.* $6^h\ 34^m\ 53^s$, N. 10° 0′·3. Max. 4·9; min. 5·4. Period, $3^d\ 10^h\ 38^m$. It is the chief star of the cluster H. VIII. 5, and has two close companions of the 9th and 11th magnitudes.

16. *ζ Geminorum.* $6^h\ 56^m\ 59^s$, N. 20° 44′·7. Max. 3·7; min. 4·5 m. Period, $10^d\ 3^h\ 43^m\ 12^s$. Pickering thinks it probable that this star is a surface of revolution, one side being about four-fifths of the brightness of the other.

17. *R Geminorum.* $7^h\ 0^m\ 7^s$, N. 22° 53′·3. Max. 6·6–7·3; min. below 12 m. Mean period, 371 days. Knott found it rising to a maximum 1885, May 11 (mag. 7·3). It is Lalande 13739.

18. *L_2 Puppis.* $7^h\ 9^m\ 52^s$, S. 44° 26′·7. A southern variable discovered at Cordova in 1872. It varies from 3·5 to 6·3, with a period of about 136 days. A maximum was observed by Stanley Williams 1886, Jan. 20, mag. 3·55; he finds a mean period of 136·05 days with epoch maximum = 1878, March 16·0 (*Observatory*, Sept. 1886).

19. *π Puppis.* $7^h\ 12^m\ 56^s$, S. 36° 53′·0. Max. 2·3; min. 3·3. A variable discovered at Cordova; variation confirmed by Stanley Williams.

20. *U Monocerotis.* $7^h\ 25^m\ 4^s$, S. 9° 31′·6. Max. 6·0; min. 7·2. Period, 31 to 50 days. Max. 1885, March 5, and min. 1885, Jan. 4·5 (Sawyer).

21. *R Cancri.* $8^h\ 9^m\ 57^s$, N. 12° 5′·6. Max. 6·8–8·3 m.; min. below 11·7 m. Mean period, 354·4 days. Max. 1882, Oct. 5 (6·5 m.) and 1883, Oct. 23 (6·5 m.), (Schmidt). Spectrum of the third type.

22. *V Cancri.* $8^h\ 14^m\ 53^s$, N. 17° 40′·0. Max. 6·8–7·7 m.; min. below 12 mag. Mean period, 272 days. A maximum was observed by Sawyer 1883, April 17; mag. 7·7.

23. *R Carinæ.* $9^h\ 29^m\ 14^s$, S. 62° 15′·5. A remarkable southern variable, discovered at Cordova. Max. 4·3–5·4 m.; min. 9·3 m. Period about 313 days. It is a very red star, and was described by Sir John Herschel, when at the Cape, as 'a very in-

tense sanguine star between scarlet and carmine-red.' Maxima were observed by Tebbutt at Windsor, N.S.W., 1880, Dec. 16, 1881, Oct. 21, and 1882 Sept. 2; and minima, 1880, July 5, 1881, June 8, 1882, March 27, and 1883, Feb. 7.

24. *R Leonis Minoris.* $9^h\ 38^m\ 23^s$, N. 35° 3′·9. Max. 6·1–7·5; min. below 11 m. Mean period, 374·7 days. Maxima were observed by Sawyer 1884, July 20 ± (mag. 7·4), and 1885, June 26 (mag. 6·8). Dunér finds a spectrum of the third type, with very large and dark bands even in the blue.

25. *R Leonis.* $9^h\ 41^m\ 6^s$, N. 11° 59′·2. A remarkable and interesting variable. It lies closely south of 19 Leonis. Max. 5·2–6·7; min. 9–10 m. Mean period, 312·6 days. A maximum was observed by Sawyer 1884, Dec. 24 (mag. 5·3). It is very red in all its phases of light. The spectrum is a fine example of the third type.

26. *l Carinæ.* $9^h\ 41^m\ 57^s$, S. 61° 57′·2. Max. 3·7; min. 5·2 m. Period about 31·25 days.

27. *R Antliæ.* $10^h\ 4^m\ 35^s$, S. 37° 8′·6. Max. 6·5; min. below 8 m. Period undetermined.

28. *S Carinæ.* $10^h\ 5^m\ 33^s$, S. 60° 57′·8. Max. 6¼; min. 9 m. Period, several months.

29. *U Hydræ.* $10^h\ 31^m\ 37^s$, S. 12° 45′·6. Max. 5·0–5·2; min. 6·1–6·3. Period about 195 days, according to Espin; max. 1883, April 25. It has a remarkable spectrum of Secchi's fourth type, which Dunér describes as 'd'une beauté extraordinaire.'

30. *R Ursæ Majoris.* $10^h\ 36^m\ 8^s$, N. 69° 24′·3. Max. 6·0–8·1; min. about 13 m. Mean period, 302·22 days. Maxima 1884, Aug. 29, and 1885, July 1 (mag. 7·5) (Sawyer). Sawyer finds the increase of light very rapid, but the decrease sometimes slow and irregular. It has a spectrum of the third type.

31. *η Argûs.* $10^h\ 40^m\ 25^s$, S. 59° 3′·1. A very remarkable variable star in the southern hemisphere, which has varied through all grades of brilliancy, from the brightness of Sirius to below 7 m.! (its brightness in the years 1877–86, according to Tebbutt). Its period has not been accurately determined, but it would seem to be very long. A period of 46 years was suggested by Wolf, and a period of 67 years by Loomis, but Schönfeld thinks that a *regular* period is very improbable. The star

lies in a very remarkable nebula, in which some observers consider that decided changes have taken place since Sir J. Herschel examined it with his 20-foot reflector at the Cape. The spectroscope shows that the nebula consists of glowing gas, one of the constituents being hydrogen.

32. *T Carinæ.* $10^h\ 50^m\ 30^s$, S. 59° 52′·8. Max. 6·2; min. 6·9. Period undetermined. Discovered by Thome at Cordova in 1872.

33. *R Corvi.* $12^h\ 13^m\ 25^s$, S. 18° 35′·1. Max. 6·8–7·3; min. below 11·5. Mean period, 318·6 days. Dunér finds a spectrum of the third type with large and dark bands, especially in the green-blue.

34. *R Virginis.* $12^h\ 32^m\ 25^s$, N. 7° 38′·9. Max. 6·5–7·5; min. 10–10·9 m. Mean period, 145·7 days. Maxima were observed by Sawyer 1884, April 11 (mag. 7·1), and 1885, June 13 (mag. 7·0). Dunér finds a spectrum of Secchi's third type.

35. *R Muscæ.* $12^h\ 34^m\ 45^s$, S. 68° 45′·0. Max. 6·6; min. 7·4. Period, 0·89 day. The minima precede the maxima by 9 hours.

36. *R Hydræ.* $13^h\ 23^m\ 10^s$, S. 22° 39′·6. Max. 4·0–5·5 m.; min. about 10 m. Mean period about 436 days, but diminishing. According to Schmidt, the minimum occurs about 200 days before the maximum. Recent maxima were observed by Schmidt 1882, March 8, and 1883, May 15·0; by Gore 1883, May 12–16; and by Sawyer 1884, July 10–30 (mag. 4·2). The spectrum is a fine example of the third type, according to Dunér 'd'une beauté tout à fait extraordinaire,' the bands being extremely large and perfectly black.

37. *S Virginis.* $13^h\ 26^m\ 44^s$, S. 6° 34′·6. Max. 5·7–7·8; min. about 12·75. Mean period, 374 days. A minimum was observed by Knott 1883, July 4.

38. *R Centauri.* $14^h\ 7^m\ 56^s$, S. 59° 21′·2. Mag. 6 m.; min. 10 m. Period undetermined. Near β Centauri. A bright 'temporary star' is recorded in the Chinese Annals as having appeared A.D. 173 between α and β Centauri, which may possibly have been an outburst of this variable.

39. *D M* + 39°, 2773 *Bootis.* $14^h\ 24^m\ 54^s$, N. 39° 23′·9. Max. 6·7; min. 9·5 m. Discovered by Dunér in 1884. Mean period, 266·5 days. Called V Bootis in Professor Pickering's list. Dunér observed a maximum 1885, June 1 (7·2 m.), and minima

1885, Jan. 28 and Oct. 23 (9·4 m.), and finds a fine spectrum of the third type even when the star is at a minimum.

40. *R Bootis.* $14^h\ 31^m\ 54^s$, N. 27° 15′·6. Max. 5·9–7·8; min. 11–12 m. Mean period, 223 days. Maxima were observed by Sawyer 1884, Oct. 5 (mag. 7·4), and 1885, May 16 (mag. 7·8.) Dunér finds a spectrum of the third type.

41. 34 *Bootis.* $14^h\ 38^m\ 9^s$, N. 27° 2′·4. Max. 5·2; min. 6·1. Schmidt deduced a period of 361 days, with a maximum on Feb. 24, 1876, and remarkable anomalies in the light curve. The variability was confirmed by Schwab. It has a spectrum of the third type. It lies closely *s.p.* ε Bootis, and owing to its proximity to this bright star it is somewhat difficult of observation.

42. δ *Libræ.* $14^h\ 54^m\ 34,^s$ S. 8° 2′·4. Max. 4·9; min. 6·1. A variable of the Algol type; period $2^d\ 7^h\ 51^m\ 20^s$. The variation occupies about 12 hours, of which the decrease takes 5½ hours. The period is, according to Schönfeld, affected by inequalities, which Schmidt considers may be represented by a nine-years' cycle.

43. *T. Trian. Australis.* $14^h\ 58^m\ 35^s$, S. 68° 15′·5. Max. 7·0; min. 7·4 m. Period, 1 day ±.

44. *R Trian. Australis.* $15^h\ 9^m\ 3^s$, S. 66° 3′·3. Max. 6·6; min. 8·0. Period, 3·4 days. The minimum precedes the maximum by about 48 hours.

45. *S Coronæ.* $15^h\ 16^m\ 38^s$, N. 31° 48′. Max. 6·1–7·8; min. about 12 m. Mean period, 360·4 days. Maxima were observed by Sawyer 1884, May 5 (7·3 m.), and 1885, May 11 (7·7 m.). The rise from minimum to maximum occupies about 126 days, according to Baxendell, who gives the following elements:

$$\text{Epoch max.} = 1875, \text{June } 27{\cdot}0 + 360^d{\cdot}416\,E.$$

It has a spectrum of Secchi's third type, with dark and very large bands (Dunér).

46. *R Coronæ.* $15^h\ 43^m\ 38^s$, N. 28° 31′·6. Max. 5·8; min. about 13 m. A very irregular variable, sometimes remaining at or near a maximum for a whole year or longer, and then rather suddenly descending to a minimum.

47. *R Serpentis.* $15^h\ 45^m\ 10^s$, N. 15° 29′·9. Max. 5·6–7·6;

min. below 11 m. Mean period, 357·6 days, but affected by large irregularities. A maximum occurred 1870, April 25·6. Knott observed the star at the mag. 11·5 on April 20, 1885. Vogel and Dunér find a spectrum of the third type, and Dunér calls it 'très beau.'

48. *U Herculis.* $16^h\ 20^m\ 29^s$, N. 19° 10′·1. Max. 6·6–7·7; min. about 11½ m. Mean period, about 408·3 days. A very red star. Dunér finds a spectrum of the third type, with very large and dark bands. A maximum was observed by Baxendell 1885, July 14 (mag. 7·4), and by Sawyer 1885, July 8 (mag. 7·8).

49. *g* (30) *Herculis.* $16^h\ 24^m\ 42^s$, N. 42° 8′·9. Max. 5 m.; min. 6·2 m. Period varies from 40 to 125 days. In 1882 Schmidt found a mean period of 91 days. The spectrum is a fine example of Secchi's third type.

50. *S Herculis.* $16^h\ 46^m\ 27^s$, N. 15° 8′·7. Max. 5·9–7·7; min. 11·5–12·2. Mean period, 303 days. A maximum was observed by Baxendell 1884, July 24 (mag. 7·7), and 1885, June 11 (mag. 6·4). Vogel and Dunér find a spectrum of the third type. It lies close to the star 49 (Fl.) Herculis, in fact so close that a small telescope will be required to observe the star at maximum. 49 Herculis forms an excellent comparison star, its magnitude, as measured at Harvard, being 6·41 m.

51. *a Herculis.* $17^h\ 9^m\ 11^s$, N. 14° 37′·8. Max. 3·1; min. 3·9 m. Period very irregular, and, according to Schönfeld, often scarcely perceptibly variable. The period, according to Argelander, varies from 26 to 103 days. In 1882 Schmidt found periods of 87 and 121 days, and in 1883 periods of 54 and 60 days. The spectrum is a remarkable example of the third type, with very large and black bands (Dunér).

52. *U Ophiuchi.* $17^h\ 10^m\ 29^s$, N. 1° 20′·6. Max. 6·0; min. 6·7. A remarkable variable of the Algol type, discovered by Sawyer in 1881. It has the shortest period of any known variable, viz. $20^d\ 7^h\ 41·6^m$. All the light changes take place in about four hours. Observations by Chandler and Sawyer show a curious 'standstill' in the light for some 15 minutes shortly after the minimum. It is a double star h 854, the *comes* being 17 m., distance 20″·54, P = 358°·8 (Burnham).

53. *u* (68) *Herculis.* $17^h\ 12^m\ 53^s$, N. 33° 13′·8. Max. 4·6;

min. 5·4. Period, 37 to 40 days (Schmidt), with anomalies, especially at the minimum, when fluctuations of a few steps take place in periods of 24 to 26 hours, and last about three days. Schmidt gives extremes of 4 m. and 6 m., but these are seldom attained. It is a double star, O. Σ 328, the companion being 10·1 m., distance about 4″, P = 60°·6 (Burnham, 1878).

54. *X* (3) *Sagittarii.* $17^h\ 40^m\ 0^s$, S. 27° 47′·0. Max. 4 m.; min. 6 m. Period, 7·01185 days.

55. *W* (γ′) *Sagittarii.* $17^h\ 57^m\ 21^s$, S. 29° 35′·2. Max. 5; min. 6·5. Period, 7·59327 days.

56. *T Herculis.* $18^h\ 4^m\ 33^s$, N. 31° 0′·2. Max. 6·9–8·3; min. 11·4–12·9. Mean period, 165·1 days. Maxima were observed by Baxendell, 1884, May 30 (mag. 7·4); 1884, Nov. 8 (mag. 6·9); and 1885, April 28 (mag. 7·9); and minima 1884, Aug. 23, and 1885, July 20 (mag. 12·9).

57. — *Sagittarii.* $18^h\ 14^m\ 20^s$, S. 18° 54′.7. Max. 5·6; min. 6·6. A short-period variable, discovered by Sawyer in Sept. 1886. His observations show that the period is about 5·75 days. The star is No. 57 of Sagittarius in the 'Uranometria Argentina.'

58. *U Sagittarii.* $18^h\ 24^m\ 49^s$, S. 19° 12′·6. Max. 7·0; min. 8·3. Period, 6·74518 days.

59. *R Scuti.* $18^h\ 41^m\ 5^s$, S. 5° 49′·9. Max. 4·7–5·7; min. 6·0–8·5. Period variable. From good observations of minima in 1882 Schmidt deduced a period of 168 days (*Ast. Nach.* 2491). From observations in 1885 Sawyer found periods of 54 to 72 days. Schmidt and Schönfeld find that bright and faint minima usually occur alternately.

60. κ *Pavonis.* $18^h\ 44^m\ 36^s$, S. 67° 23′·0. Max. 4·0; min. 5·5 m. Period, 9·1 days. Discovered by Thome in 1872 at Cordova.

61. β *Lyræ.* $18^h\ 45^m\ 39^s$, N. 33° 13′·3. Max. 3·4; min. 4·5 m. Period, 12·9078 days. There are two maxima of 3·4, and two minima, one 3·9 m., and one (the chief minimum) of 4·5 m. According to Professor Pickering's theory of short-period variables, this variable is a surface of revolution, the ratio of the axes being as 5 : 3, with the dark portion at one of the ends, and symmetrically situated as regards the larger axis.

62. *R* (13) *Lyræ.* $18^h\ 51^m\ 41^s$, N. 43° 47′·5. Max. 4·3 m.; min. 4·6 m. Mean period about 46 days, but somewhat irre-

gular. Particularly bright phases were observed by Sawyer 1883, Aug. 6 and Aug. 31, and 1884, Nov. 7–12 and Nov. 21–30. 'The increase of its light from its normal brightness at maximum amounted to about half a magnitude' (*Ast. Nach.* 2660). The spectrum is a fine example of the third type. Dunér says: 'Le spectre est un des plus superbes de cette classe.'

63. *R Aquilæ.* $19^h\ 0^m\ 36^s$, N. 8° 3′·1. Max. 6·4–7·4; min. about 11 m. Mean period, 345·1 days. Dunér finds a spectrum of the third type. The increase from 9–10 m. to 7–8 is often extraordinarily quick. A maximum was observed 1865, Feb. 10·7.

64. *U* (?) *Aquilæ.* $19^h\ 22^m\ 54^s$, S. 7° 17′·3. Max. 6·4; min. 7·3 m. A short-period variable, discovered by Sawyer in 1886. Period, 7 days ±. It is No. 50 of Aquila in the 'Uranometria Argentina.'

65. *h′* (51) *Sagittarii.* $19^h\ 28^m\ 44^s$, S. 24° 58′·8. Max. 5·3; min. 6·7. Period undetermined. Discovered at Cordova. Observations of this and other southern variables are much required.

66. *R Cygni.* $19^h\ 33^m\ 36^s$, N. 49° 55′·8. Max. 5·9–8·2; min. 13 m. Mean period, 425·3 days. According to Pogson, the minimum occurs 155 days before the maximum. Baxendell observed a maximum 1885, Feb. 20 (mag. 8·2). Dunér finds a spectrum of the third type. The star lies closely *s.f.* θ Cygni. There is a 9 m. star closely *n.f.* the variable.

67. χ *Cygni.* $19^h\ 45^m\ 57^s$, N. 32° 36′·7. A remarkable and interesting variable. Max. 4·0–6·0; min. 12·8. Mean period, 406·5 days, but subject to marked irregularities. This star deserves close attention, and its maxima should be carefully observed. A maximum was observed by Sawyer and Gore 1884, Nov. 23, and another by Sawyer 1886, Jan. 10. The spectrum is a remarkable one of the third type. The star is the true χ Cygni of Bayer, and should not be confused—as has been often done—with Flamsteed's χ (17 Cygni, Flamsteed).

68. η *Aquilæ.* $19^h\ 46^m\ 21^s$, N. 0° 41′·9. Max. 3·5; min. 4·7. Period, $7^d\ 4^h\ 14^m\ 4^s$. Discovered by Pigott in 1784.

69. *S* (10) *Sagittæ.* $19^h\ 50^m\ 34^s$, N. 16° 19′·0. Max. 5·6; min. 6·4. A short-period variable, discovered by Gore in 1885. From a discussion of the observations up to May 1886, Chandler deduces a period of 8·38264 days, with mean epoch 1885 Dec.

$4^d\ 9^h\ 36^m$ G.M.T., and gives the formula for calculation of maximum—

$$M = 1885 \text{ Dec. } 4^d\ 9^h\ 36^m \text{ Gr. M.T.} + 8^d\ 9^h\ 11^m{\cdot}0\ (E - 391)$$

Duration of increase, $3^d{\cdot}00$

,, of decrease, 5·38.

(*Ast. Nach.* 2749.)

Owing to its proximity to a good comparison star, 11 Sagittæ, the variation of light, although small, will be found very evident and interesting. Espin remarks that the star is about four days visible to the naked eye and four days invisible.

70. — *Cygni.* $20^h\ 38^m\ 42^s$, N. 35° 9′·5. Max. 6·3; min. 7·6. A short-period variable, discovered by Chandler in 1886. He gives the elements—

$$1886 \text{ Oct. } 3{\cdot}40 \text{ (Cambridge M.T.)} + 14^d{\cdot}04 \text{ E.}$$

'The increase of light occupies about four days; the decrease ten days, with a halt in the latter about midway of its course.' (Gould's *Astronomical Journal*, No. 148.)

71. *T Aquarii.* $20^h\ 44^m\ 1^s$, S. 5° 33′·7. Max. 6·7–7·8; min. about 12·5 m. Mean period, 203·2 days. Maxima were observed by Schmidt 1883, Jan. 5 (7·5 m.), and 1883, July 31 (7·8 m.).

72. *T Vulpeculæ.* $20^h\ 46^m\ 24^s$, N. 27° 48′. Max. 5·5; min. 6·6. A very interesting variable of short period, discovered by Sawyer in 1885. The star is DM + 27°, 3890, and lies a little *n.p.* 32 Vulpeculæ. From observations in 1885–86 Chandler finds the following elements:

$$\text{Max} = 1885 \text{ Nov. } 2{\cdot}8576 \text{ G.M.T.} + 4^d{\cdot}4368 \text{ E.}$$

The duration of increase is 1·060 days, and that of decrease 3·377 days.

73. *Y Cygni.* $20^h\ 47^m\ 15^s$, N. 34° 12′·4. Max. 7·1; min. 7·9. A variable of the Algol type, discovered by Chandler in 1886. He gives the following approximate elements:

$$1886 \text{ Dec. } 9^d{\cdot}458. \text{ G.M.T.} + \left(\frac{5{\cdot}997}{n}\right) \text{E.}$$

Later observations give a period of $2^d\ 23^h\ 56^m$.

From his observations he concludes that n cannot be either 3 or 5, and is probably 4, 7, or possibly 8. The variations of light occupy about six hours. The star is D M + 34°, 4181.

74. *T Cephei.* $21^h\ 10^m\ 4^s$, N. 68° 0′·1. Max. 6·2–6·7; min. 9·5–9·9. From four observed maxima 1882–85, Knott deduces a period of 392·0 days, with epoch 1884, March 6, and from five minima, 1881–85, a period of 385·4 days with epoch Aug. 7, the former elements agreeing better with observation than the latter. The increase of light is slower than the decrease. 'The star has a fine spectrum with dark bands of considerable intensity.' Knott's observations in 1886 show a maximum about March 26 ±, mag. 6·2; minimum, Oct. 16, mag. 9·6.

75. *W Cygni* (= Birm. 587 = D M 44°, 3877). $21^h\ 31^m\ 30^s$, N. 44° 50′·4. Max. 5·8 ±; min. 7 ±. Period, 118 to 130 days. A variable discovered by Gore in 1884. Gore's observations show maxima about Dec. 23, 1884, Aug. 19, 1885, Dec. 16, 1885, and May 19, 1886; and minima about June 9, 1885, Oct. 22, 1885, and Feb. 14, 1886. Sawyer observed maxima 1885, Aug. 20, and 1885, Dec. 16, and a minimum 1885, Oct. 30. The star is very red, and lies a little *s.f.* ρ Cygni. The spectrum is a fine example of the third type. Dunér describes it as 'd'une beauté extraordinaire,' with very large and very black bands.

76. *μ Cephei.* $21^h\ 39^m\ 50^s$, N. 58° 13′·8. Sir W. Herschel's 'garnet star,' the reddest of all the stars, visible to the naked eye in the northern hemisphere. Argelander and Hind considered the variation certain. Numerous observations by Gore, 1883 to 1887, vary from 3·8 to 4·8, and show that the star is certainly variable, but the period seems irregular. A very bright phase was observed by Gore on Feb. 13, 1885, and May 11, 1885, when μ was very little inferior to ζ Cephei. Owing to its very red colour—and at times strong scintillation—the star is a difficult object to observe. The spectrum is a very perfect one of Secchi's third type, 'the separating spaces being sharp, dark, and very broad.'

77. *δ Cephei.* $22^h\ 24^m\ 43^s$, N. 57° 48·1. Max. 3·7; min. 4.9. A short-period variable discovered by Goodricke in 1784. Period, $5^d\ 8^h\ 47^m\ 39^s{\cdot}97$. The period shows some irregularities. It is a wide double star, somewhat like β Cygni.

78. *β Pegasi.* $22^h\ 57^m\ 58^s$, N. 27° 25′·8. Max. 2·2; min. 2·7. Variation irregular, according to Schönfeld. In 1883 Schmidt found a mean period of 29·7 days. Observations by Sawyer

from 1884, Aug. 1, to 1885, June 1, showed only slight fluctuations of light of 'not more than a couple of steps,' and in 1885, Jan. 10 to Feb. 3, and July 15, 1885, to Jan 1, 1886, he found the light 'apparently constant.'

79. *R Pegasi.* $23^h\ 0^m\ 37^s$, N. 9° 53′·7. Max. 6.9–7·7; min. about 12 m. Mean period about 382 days. A maximum 1886, Aug. 3.

80. *R Aquarii.* $23^h\ 37^m\ 37^s$, S. 15° 57′·1. Max. 5·8–8·5; min., about 11. The period has been discussed by Chandler, and he concludes that, 'instead of a uniform period, we must assume a variable one, with a mean value of 387·4 days, which runs through the cycle of its irregularities in 44·4 or 41·86 single periods.' He gives the following formula for the calculation of the time of maximum:—

$$1843, \text{Sept. } 20^d{\cdot}86 + 387{\cdot}394\ E + 33{\cdot}9 \sin.\ (8^\circ{\cdot}6\ E + 170^\circ\ 20'),$$

which, however, he considers must be further corrected by future observations. A maximum was observed by Sawyer 1885, Jan. 4 (mag. 7·1). Dunér finds a spectrum of the third type, with large dark bands.

81. 19 *Piscium.* $23^h\ 40^m\ 15^s$, N. 2° 49′·2. Max. 4·8–5·2; min. 6·2. Variation observed at Cordova. From observations of this red star 1881–84 Espin finds a variation of 5·1 to 6·3, with a period of about 165 days, and gives the following provisional elements:

$$\text{Epoch max.} = 1884, \text{Aug. } 19 + 165^d \pm.$$

He finds the star orange at maximum, and orange-red at minimum. Gore's observations confirm the variability. Dunér finds a 'superbe' spectrum of the third type with large strong bands. Vogel's observations agree with Dunér's in all essential details.

82. *R Cassiopeiæ.* $23^h\ 52^m\ 19^s$, N. 50° 43′·1. Max. 4·8–6·8; min. below 12 m. Mean period about 433 days. Observations of this star are very desirable. Elements given by Schönfeld fix a maximum for Oct. 21, 1885; but a maximum was observed by Baxendell 1885, Feb. 6 (mag. 6·1), and by Gore 1886, April 14 (mag. 5·6 ±). Maxima were also observed by Schmidt 1879–83. Treating the observed maxima since 1879 by the method of least squares, Gore finds the following elements:

$$\text{Max.} = 1882, \text{Sept. } 18 + 433^d{\cdot}41\ E.$$

APPENDIX II.

SUSPECTED VARIABLE STARS.

Many of the stars in the following list are probably variable—some are undoubtedly so—and careful observation would probably lead to the discovery of a number of new variables. Most of them may be well observed with a good opera-glass.

Star	R.A. 1880	Decl. 1880	Supposed change of magnitude	Authority	Remarks
	h. m. s.	° ′			
D.M. 81°, 18 Cephei .	0 40 8	+81 19	—	Pickering, Knott	Near U Cephei
D.M. 8°, 215 Piscium .	1 15 16	+ 9 3	$9\frac{1}{2}$ – 0	Tempel	
Lalande 2598 Ceti . .	1 19 46	− 4 35	$6\frac{1}{2}$ – 8	Gould	Gould says 'certainly variable'
Lalande 2798 Ceti . .	1 25 29	− 7 20	6·9 – $8\frac{1}{2}$	Gould	6·9 Gould—below 8 m. Gore, Dec. 21, 1884; 7·5 m. Markwick, 1886, Nov. 29, 1887, Feb. 12
100 Piscium	1 28 23	+12 0	7 – 9	Borelly, 1885	
V Piscium	1 48 2	+8 11·5	6 – 9	Argelander	
740 B.A.C. Cassiopeiæ .	2 20 19	+81 7	6 – $8\frac{1}{2}$	Baily	6 m. Franks, Nov. 1877; 9 m. Gore, March 1884
Lalande 4864 Persei .	2 32 12	+49 3	$6\frac{1}{2}$ – 9		
Bradley 396 Cass. . .	2 52 57	+81 0·5	$4\frac{1}{2}$ – 7		
β Persei (comes) . .	3 0 22	+40 30	10 – 14	Schröter, Sadler	
30 (e) Tauri	3 41 41	+10 46	5 – 6	Franks	5 Heis; 6 Franks; 5·5 Gore
Lalande 7172 Tauri .	3 46 45	+ 7 25	6·8 – 7·9	Gould	7·8 m., Markwick, 1887, Jan. 12
U Tauri	4 14 49	+19 32	—	Baxendell	
839 H. Tauri	4 14 57	+19 14	var. nebula	D'Arrest	
π^1 Orionis	4 43 18	+ 6 45	3 – 5	Gould, Espin, Gage	
Birmingham 85 Tauri	4 44 0	+28 19	$7\frac{1}{2}$ – 10	Birmingham	

Suspected Variable Stars—continued.

Star	R.A. 1880	Decl. 1880	Supposed change of magnitude	Authority	Remarks
	h. m. s.	° ′			
5 Orionis	4 47 7	+ 2 18	5·6 – 6·6	Gould	
Lalande 9418 Orionis .	4 54 13	+ 3 26	—	Gould	
B. II 16 Leporis . . .	5 6 10	– 12 2	5½ – 7½	Espin Morton	Certainly variable
Anon. Tauri	5 27 41	+ 21 52	8½ – 11½	Schmidt	
Lalande 10527 Orionis	5 29 10	– 6 5	5½ – 7½	Falb Gould	
Bond 654 Orionis . .	5 29 57	– 5 28	11·5 – 0		
Bond 822 Orionis . .	5 29 57	– 5 33	9·7 – 12·8	Schmidt, 1878 Common, 1883	Seems certainly variable
υ Aurigæ	5 42 50	+ 37 16	4·3 – 5·3	Espin	
35 Aurigæ	5 54 58	+ 51 34	5½ – 8	Dembowski	
39 Aurigæ	5 56 24	+ 42 59	5·4 – 6·2	Gore, 1878	
B. 144 Geminorum . .	6 18 37	+ 14 47	6½ – 8	Birmingham	
B. 147 Geminorum . .	6 24 26	– 2 56	5½ – 8	Birmingham	
O.A. 5270 Can. Majoris	6 28 7	– 27 51	6 – 9½	Gould	
Lalande 13627 Monoc.	6 56 4	– 5 33	5·4 – 6·1	Gore, 1884	
Lalande 14551 Puppis	7 22 13	– 11 19	5·9 – 6·6	Espin, 1883	
W.B. 669 Monocerotis	7 23 15	– 1 39	4½ – 9	Olbers	
Lacaille 3344 Argûs .	8 24 25	– 26 56	6 – 8	Gould	
— Cancri	8 50 23	+ 11 23·4	7·7 – 8·6	Baxendell	
3180 B.A.C. Argûs . .	9 13 27	– 23 58	6 – 8½	Gould	
α Hydræ	9 21 41	– 8 8	—	Sir J. Herschel Gemmill	
ψ Leonis	9 37 12	+ 14 34	6 – 0	Montanari, 1667	
— Sextantis	9 41 2	+ 7 11	6 – 9	Borelly, 1885	
Lalande 19662 Sextans.	9 57 46	– 9 0	4½ – 7	Gore, 1875	
Lalande 19992 Leonis	10 11 49	+ 13 18	6 – 10	Borelly, 1885	

α Ursæ Majoris . . .	10 56 18	+62 24	and var. colour	Harding, Klein	
— Virginis	12 7 45	+ 0 15	—	Harrington, 1881	
δ Ursæ Majoris . .	12 9 29	+57 42	—	Schmidt	
Birm. 277 Virginis . .	12 19 7	+ 1 27	6 – 8	Birmingham	
β Corvi	12 28 5	−22 44	1 mag.	Smyth, Gould, Sawyer	
B. 290 Can. Venatici .	12 39 29	+46 6	4½ – 6½	Schmidt	Certainly variable
— Virginis	13 8	−15 56	6 – 9	Olbers, 1797	
83 Ursæ Majoris . .	13 36 11	+55 17	3·7 – 5·3	Birmingh'm, 1868	Equal to δ, Aug. 6, 1868
— Virginis	14 7 40	−11 18			
B 327 Bootis	14 18 24	+ 8 38	6 – 7½	Birmingham	
U Bootis	14 35	+27 59	9½ – 13	Baxendell, 1864	
ε Bootis	14 39 44	+27 35	—	Baxendell	
β Ursæ Minoris . . .	14 51 4	+74 39	2·2 – 2·8	Sir J. Herschel, Struve, Espin	
Struve 1932 Coronæ .	15 13 11	+27 16	—	Struve	Variation confirmed by Gore
τ⁴ Serpentis	15 30 54	+15 30	6 – 0	Birmingham	
Anon. Cor. Borealis . .	15 43 35	+28 38	11 – 13	Schmidt	
ζ Ursæ Minoris . . .	15 48 22	+78 10	4·2 – 4·7	Espin	
B. 372 Serpentis . .	16 3 35	+ 1 8	6 – 7½	Birmingham	
B. 379 Ophiuchi . .	16 20 4	−12 9	7·5 – 10·5	Birmingham	Variation confirmed by Dunér
B. 418 Serpentis . .	17 37 53	−18 36	7½ – 0	Birmingham	
B. 420 Ophiuchi . .	17 48 8	+ 1 47	7½ – 0	Birmingham	Below 8½ m. Gore, Sept. 2, 1886
O.A. 17670. Sagittarii	18 0 51	−17 10	4½ – 7	Gould	
B. 487 Vulpeculæ . .	19 3 37	+23 59	6 – 7½	Birmingham	
β Cygni	19 25 53	+27 42	3·3 – 3·9	Klein, Webb	
D.M. 17°, 3997 Sagittæ	19 27 16	+17 28	6 – 0		
Lalande 37621 Cygni .	19 40 8	+34 7	6 – 7	Köhl, 1878	
Lalande 37868 Vulp. .	19 46 59	+24 41	5 – 7	Schmidt	
η Cygni	19 51 48	+34 46	—	Sir J. Herschel	1842
B 541 = D.M. 38,° 3957	20 9 2	+38 22	6 – 8·0 ±	Espin	

Suspected Variable Stars—continued.

Star	R.A. 1880	Decl. 1880	Supposed change of magnitude	Authority	Remarks
	h. m. s.	° ′			
V Capricorni	20 10 5	−21 41	6½ − 8½	Secchi Gore	Variation confirmed by Safarik
B. 558 Delphini . . .	20 19 58	+ 9 40	6 − 0	Birmingham Gould Lynn	6·5 m. Gore, 1885, Sept. 10 and Nov. 4
ρ Capricorni	20 22 1	−18 12	4 − 6	Borelly	
Anon. Capricorni . .	20 23 51	−12 38	6¾ − 8½	Gould	
Near α Cygni	20 37 25	+47 43	8½ − 12	Birmingham Baxendell	Certainly variable
B. 569 Delphini . . .	20 39 58	+17 39	6·3 − 8	D'Arrest Espin	Certainly variable. Variation confirmed by Gore
B. 573 Delphini . . .	20 51 36	+15 47	6½ − 0	Birmingham	
Ll. 40866 Capricorni .	21 0 30	−16 15	7 − 9	Borelly	
33 Capricorni . . .	21 17 21	−21 22	5½ − 7½	Chacornac	
B. 596 Aquarii . . .	21 40 19	− 2 46	1 mag.	Birmingham Espin	Certainly variable
B. 607 Lacertæ . . .	22 43	+39 7	4½ − 7½	Secchi	
Anon. Aquarii . . .	22 23 4	−10 33	7·8 − 0	Rumker	
ζ Piscis Australis . .	22 24 13	−26 41	—	Schmidt Peters	
Lalande 44782 Piscium	22 47 38	+ 1 12	6½ − 8	Gould	Below 7 m. Markwick, 1887, Jan. 12
ψ^3 Aquarii	23 12 42	−10 16	—	Schmidt	
8122 B.A.C. Cephei .	23 13 13	+73 2	6 − 10	Liouville, 1856 Franks, 1877	
B. 637 Pegasi . . .	23 14 15	+22 26	5 − 0	Birmingham	
Lalande 45980 Aquarii	23 23 18	− 5 11	6·3 − 7¼	Gould	6·5 m. Markwick, Nov. 29, 1886
Lalande 46090 Aquarii	23 26 12	−11 40	6 − 7	Schmidt, 1878	
ι Andromedæ	23 32 15	+42 36	4 − 7		
3 Ceti	23 58 21	−11 10·5	4·9 − 5·9	Gould	

APPENDIX III.

COMPARISON STARS.

List of stars brighter than the fourth magnitude as measured with the photometers at Oxford and Harvard. Oxford standard, Polaris = 2·05 m. Harvard standard, Polaris = 2·15 m.

(A) Stars North of the Equator.

Star	Magnitude Oxford	Magnitude Harvard	Star	Magnitude Oxford	Magnitude Harvard
Capella (α Aurigæ)	+0·92[1]	+0·82	ε Bootis . . .	2·47	2·56
Vega (α Lyræ) .	+0·86	+0·81	δ Leonis . . .	2·55	2·75
Arcturus . . .	+0·69	+0·97	α Cephei . . .	2·57	2·58
Procyon . . .	+0·50	+0·54	ζ Herculis . . .	2·64	3·09
α Orionis . . .	+0·02	+0·09	α Serpentis . .	2·67	2·71
α Aquilæ . . .	1·04	+0·03	β Herculis . .	2·67	2·76
Aldebaran . .	1·12	1·00	η Boötis . . .	2·74	2·89
Regulus . . .	1·17	1·42	β Arietis . . .	2·75	2·79
α Cygni . . .	1·32	1·47	η Draconis . .	2·79	2·82
Pollux	1·36	1·12	δ Cygni	2·79	3·05
Castor	1·53	1·56	γ Aquilæ . . .	2·81	2·77
η Ursæ Majoris .	1·77	2·02	δ Cassiopeiæ . .	2·89	2·84
γ Orionis . . .	1·79	1·86	β Ophiuchi . .	2·92	2·90
β Tauri	1·79	1·90	η Pegasi . . .	2·95	3·06
ε Ursæ Majoris .	1·80	1·85	β Draconis . .	2·96	2·97
α Ursæ Majoris .	1·89	1·96	δ Draconis . .	2·96	3·21
α Persei . . .	1·93	1·94	ζ Tauri	3·00	2·98
β Aurigæ . . .	1·94	2·07	ε Virginis . . .	3·01	3·00
α Andromedæ .	2·05	2·08	β Cygni . . .	3·02	2·99
Polaris	2·05	2·15	γ Ursæ Minoris .	3·02	3·18
β Leonis . . .	2·07	2·23	θ Aurigæ . . .	3·03	2·67
γ Leonis . . .	2·12	2·24	γ Persei . . .	3·06	3·11
γ Geminorum .	2·13	2·00	ζ Aquilæ . . .	3·08	3·10
α Arietis . . .	2·13	2·04	ζ Cygni	3·09	3·48
γ Andromedæ .	2·14	2·14	ζ Persei . . .	3·09	3·10
β Ursæ Majoris .	2·17	2·60	β Canis Minoris .	3·11	3·07
γ Cassiopeiæ . .	2·19	2·30	δ Persei . . .	3·11	3·18
β Andromedæ .	2·21	2·21	η Tauri . . .	3·12	3·00
α Ophiuchi . .	2·23	2·18	β Trianguli . .	3·12	3·12
α Coronæ . . .	2·23	2·37	μ Ursæ Majoris .	3·12	3·12
γ Cygni . . .	2·26	2·31	θ Ursæ Majoris .	3·12	3·22
γ Ursæ Majoris .	2·30	2·56	ε Persei	3·13	3·04
β Cassiopeiæ . .	2·32	2·42	γ Lyræ	3·16	3·31
α Pegasi . . .	2·33	2·61	α Lyncis . . .	3·16	3·44
γ Draconis . .	2·40	2·35	κ Ophiuchi . .	3·17	3·37
ε Pegasi . . .	2·43	2·41	δ Andromedæ .	3·18	3·41
ε Cygni	2·45	2·69	γ Bootis . . .	3·21	3·10

[1] This notation denotes that the star is 0·92 mag. brighter than an average star of the first magnitude.

Comparison Stars—continued.

Star	Magnitude Oxford	Magnitude Harvard	Star	Magnitude Oxford	Magnitude Harvard
ψ Ursæ Majoris	3·21	3·12	41 Arietis	3·58	3·78
ι Ursæ Majoris	3·23	3·17	π Herculis	3·60	3·36
δ Herculis	3·25	3·26	η Herculis	3·60	3·69
ι Draconis	3·26	3·35	θ Geminorum	3·60	3·74
θ Aquilæ	3·26	3·39	ι Cephei	3·61	3·62
λ Aquilæ	3·27	3·62	π^1 Orionis	3·62	3·33
ε Geminorum	3·29	3·19	κ Ursæ Majoris	3·62	3·70
ζ Draconis	3·29	3·27	κ Geminorum	3·63	3·61
ζ Pegasi	3·29	3·59	γ Piscium	3·63	3·82
Cor. Caroli	3·32	3·00	τ Herculis	3·63	3·87
ο Ursæ Majoris	3·36	3·43	β Bootis	3·64	3·62
δ Aquilæ	3·36	3·46	θ^2 Tauri	3·65	3·62
β Cephei	3·37	3·39	τ Cygni	3·65	3·94
ε Leonis	3·39	3·14	ε Serpentis	3·65	3·67
ξ Cephei	3·39	3·54	ο Herculis	3·67	3·99
δ Ursæ Majoris	3·41	3·41	κ Draconis	3·68	3·84
η Cassiopeiæ	3·41	3·64	ε Tauri	3·69	3·67
ζ Hydræ	3·42	3·33	η Piscium	3·71	3·66
θ Leonis	3·44	3·47	α Piscium	3·71	3·99
δ Bootis	3·44	3·50	λ Geminorum	3·72	3·58
μ Geminorum	3·45	3·22	γ Sagittæ	3·72	3·65
η Leonis	3·48	3·59	ξ Tauri	3·72	3·77
δ Geminorum	3·48	3·65	ε Draconis	3·72	3·93
η Aurigæ	3·49	3·33	ο Andromedæ	3·74	3·77
υ Ursæ Majoris	3·49	3·78	ζ Cassiopeiæ	3·75	3·74
μ Herculis	3·50	3·49	ξ Ursæ Majoris	3·75	3·80
α Trianguli	3·50	3·58	ο Leonis	3·75	3·80
γ Cephei	3·51	3·37	υ Persei	3·76	3·69
ε Cassiopeiæ	3·51	3·55	ζ Aurigæ	3·80	3·96
λ Orionis	3·52	3·49	δ Serpentis	3·80	3·96
λ Ursæ Majoris	3·52	3·57	χ Ursæ Majoris	3·80	3·89
β Delphini	3·53	3·74	λ Ophiuchi	3·81	3·97
η Cephei	3·53	3·59	γ Ophiuchi	3·83	3·82
θ Pegasi	3·53	3·76	κ Cygni	3·83	3·94
ε Hydræ	3·55	3·58	ξ Geminorum	3·84	3·36
β Serpentis	3·55	3·84	β Coronæ	3·85	3·79
γ Tauri	3·55	3·86	ζ Bootis	3·88	3·84
α Draconis	3·56	3·63	ξ Draconis	3·90	3·93
ρ Bootis	3·56	3·64	χ Draconis	3·93	3·72
ο Tauri	3·56	3·77	α Delphini	3·93	3·96
γ Herculis	3·56	3·83	τ Orionis	3·95	3·65
β Virginis	3·58	3·72	δ Aurigæ	3·98	3·79
μ Pegasi	3·58	3·74	ξ Herculis	3·99	3·91

Comparison Stars.

(B.) Stars South of the Equator.

Magnitudes estimated at Cordova ('Uranometria Argentina').

Star	Mag. U.A.	Star	Mag. U.A.	Star	Mag. U.A.
Sirius . . .	0·1[1]	ι Carinæ . .	2·5	α Hydri . .	2·9
Canopus . .	0·4	ζ Puppis . .	2·5	β Columbæ .	2·9
α Centauri .	0·7	η Centauri .	2·5	γ Velorum .	3·0
α Eridani . .	1·0	λ Velorum .	2·5	ι Centauri .	3·0
β Orionis . .	1·0	γ Corvi . .	2·5	γ Gruis . .	3·0
β Centauri .	1·2	β Scorpii . .	2·5	θ Aquilæ . .	3·0
α Crucis . .	1·3	α Columbæ .	2·5	δ Corvi . .	3·0
α Pis. Aust. .	1·4	α Lupi . . .	2·6	ν Hydræ . .	3·0
α Scorpii . .	1·4	ε Centauri .	2·6	π Sagittarii .	3·1
Spica . . .	1·5	ζ Ophiuchi .	2·6	ζ Sagittarii .	3·1
β Crucis . .	1·7	κ Scorpii . .	2·6	γ Triang. Aust.	3·1
ε Orionis . .	1·8	β Corvi . .	2·6	β Trian. Aust.	3·1
ζ Orionis . .	1·8	θ Eridani . .	2·6	α Indi . . .	3·1
ε Can. Majoris	1·8	κ Velorum .	2·7	ε Leporis . .	3·1
α Gruis . .	1·9	α Leporis . .	2·7	α Doradus .	3·1
β Carinæ . .	2·0	β Hydri . .	2·7	γ Virginis .	3·1
λ Scorpii . .	2·0	λ Sagittarii .	2·7	β Libræ . .	3·1
γ Crucis . .	2·0	ζ Centauri .	2·7	ζ Hydræ. . .	3·1
θ Scorpii . .	2·1	α Aquarii . .	2·7	β Capricorni .	3·2
α Hydræ . .	2·1	δ Ophiuchi .	2·7	μ_1 Scorpii . .	3·2
δ Can. Maj. .	2·1	π Puppis . .	2·7	τ Scorpii . .	3·2
α Pavonis . .	2·1	δ Centauri .	2·8	ρ Puppis . .	3·2
ε Carinæ . .	2·1	δ Sagittarii .	2·8	γ Lupi . . .	3·2
β Gruis . .	2·2	δ Capricorni .	2·8	υ Scorpii . .	3·2
δ Velorum .	2·2	β Lupi . . .	2·8	ζ Aræ . . .	3·2
α Triang. Aust.	2·2	β Eridani . .	2·8	γ Hydræ . .	3·2
ε Sagittarii .	2·2	β Aræ . . .	2·8	τ Puppis . .	3·2
β Can. Maj. .	2·2	α Tucanæ . .	2·8	ζ Can. Maj. .	3·2
θ Centauri .	2·2	γ Sagittarii .	2·8	γ Hydri . .	3·2
β Ceti . . .	2·3	γ Eridani . .	2.8	δ Aquarii . .	3·2
κ Orionis . .	2·3	η Can. Maj. .	2·9	θ Ceti . . .	3·2
ε Scorpii . .	2·3	ι Orionis . .	2·9	X Eridani .	3·3
σ Sagittarii .	2·4	β Leporis .	2·9	ε Corvi. . .	3·3
δ Scorpii . .	2·4	θ Carinæ . .	2·9	ι_1 Scorpii . .	3·3
γ Centauri .	2·4	α Aræ . . .	2·9	λ Aquilæ . .	3·3
α Phœnicis .	2·4	μ Velorum .	2·9	κ Centauri .	3·3
η Ophiuchi .	2·4	α Muscæ . .	2.9	ε Hydræ . .	3·3

[1] Measured + 1·97 at Oxford, and + 2·43 at Harvard.

Comparison Stars—continued.

Star	Mag. U.A.	Star	Mag. U.A.	Star	Mag. U.A.
η Sagittarii	3·3	η Ceti	3·5	ψ Velorum	3·7
β Phœnicis	3·3	ζ Ceti	3·5	η Eridani	3·7
α Reticuli	3·3	δ Museæ	3·6	δ Crateris	3·8
β Pavonis	3·3	z Eridani	3·6	η Leporis	3·8
μ Serpentis	3·3	τ Sagittarii	3·6	η Pavonis	3·8
ε Ophiuchi	3·3	ζ Leporis	3·6	ν Octantis	3·8
δ Eridani	3·3	θ Ophiuchi	3·6	ι Lupi	3·8
υ Carinæ	3·4	λ Aquarii	3·6	α Horologii	3·8
π Scorpii	3·4	ω Carinæ	3·6	ν Eridani	3·8
δ Crucis	3·4	π Hydræ	3·6	ε Phœnicis	3·8
σ Scorpii	3·4	η Scorpii	3·6	λ Ophiuchi	3·8
o_2 Can. Maj.	3·4	γ Aræ	3·6	α Pyxidis	3·8
β Museæ	3·4	p Carinæ	3·6	α Carinæ	3·8
λ Centauri	3·4	c Puppis	3·6	ι Aquilæ	3·8
G Scorpii	3·4	σ Can. Maj.	3·6	o Sagittarii	3·8
γ Phœnicis	3·4	α_2 Capricorni	3·6	τ Libræ	3·8
μ Leporis	3·4	δ Lupi	3·6	β Sagittarii	3·8
η Orionis	3·4	ζ Lupi	3·6	η Aræ	3·8
μ Centauri	3·4	ϕ_1 Lupi	3·6	λ Museæ	3·8
κ Ophiuchi	3·4	ζ_2 Scorpii	3·6	ι Gruis	3·9
λ Hydræ	3·4	ε Eridani	3·6	χ Eridani	3·9
τ Ceti	3·4	α Fornacis	3·6	υ Libræ	3·9
τ Eridani	3·4	υ_2 Eridani	3·7	μ_2 Scorpii	3·9
ζ_2 Sagittarii	3·5	ξ Serpentis	3·7	δ Columbæ	3·9
ν Ophiuchi	3·5	ζ Capricorni	3·7	β Pictoris	3·9
δ Pavonis	3·5	δ Aræ	3·7	β Doradus	3·9
ι Ceti	3·5	φ Sagittarii	3·7	φ Velorum	3·9
γ Leporis	3·5	ν Centauri	3·7	o_1 Can. Maj.	3·9
ζ Aquarii	3·5	γ Capricorni	3·7	ι Hydræ	3·9
ν Puppis	3·5	β Tucanæ	3·7	κ Phœnicis	3·9
η Serpentis	3·5	ε Lupi	3·7	β Reticuli	3·9
α Circini	3·5	χ Carinæ	3·7	β Volantis	3·9
ξ Puppis	3·5	ξ Hydræ	3·7	τ_6 Eridani	3·9
α Pictoris	3·5	η Lupi	3·7	γ Apodis	3·9
σ Puppis	3·5	δ Leporis	3·7	γ Aquarii	3·9
ε Gruis	3·5	β Indi	3·7	b_1 Aquarii	3·9
σ Libræ	3·5	c_2 Aquarii	3·7	θ Aræ	3·9
φ Eridani	3·5				

CHAPTER IX.

STAR COLOURS.

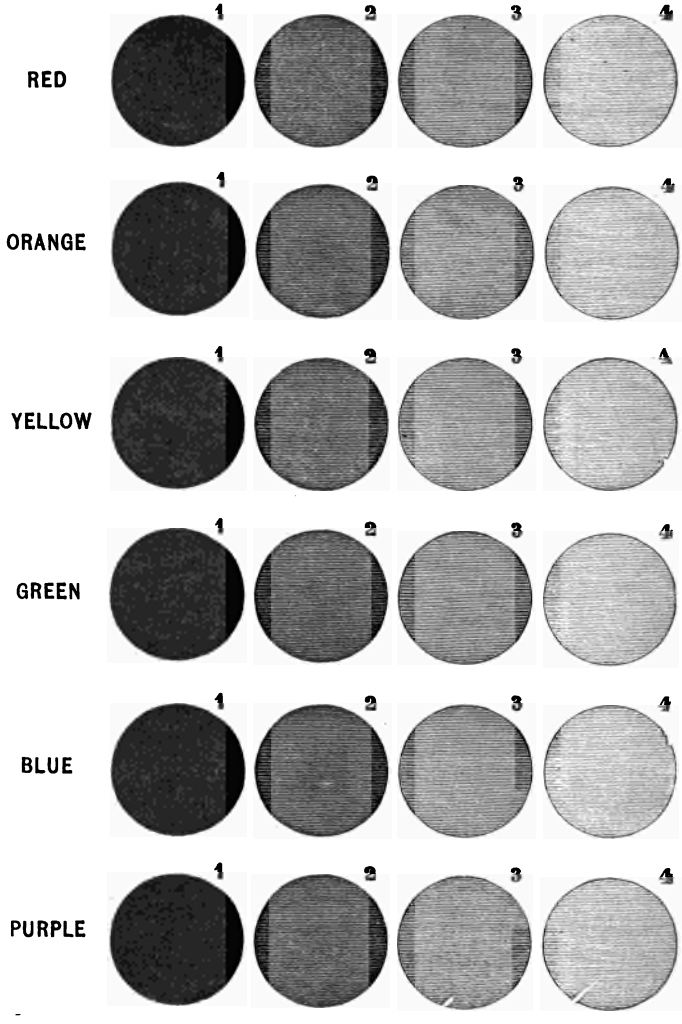
[As in the observation of variable stars, so also in the systematic study of star colours, there is presented to the amateur an interesting and promising line of work in the prosecution of which but small instrumental accessories are required. Colour estimations have long been made by stellar observers, but on comparison they are found to differ so widely, owing to personal peculiarities of sight, differences of telescopes, &c., that it is clear the work must be conducted more systematically if it is to lead to any results really worthy of the name. Colour variations in the meantime can only be said to be inferred, hardly demonstrated, as we do not know how much of the discrepancy between the results of two observations may be due to physiological, instrumental, and atmospheric causes, and how much to an intrinsic change in the star's light. Until we can in some measure eliminate these factors of error from our results, it is impossible for us to place any great degree of reliance on them, and consequently impossible to make them the basis of scientific deduction. Our present knowledge of the subject is indefinite and unsatisfactory. Nevertheless, such as it is, the observer who intends to take up this branch of research must make himself acquainted with it; and, as most of the astronomical text-

books pass it over with a few words, we give a brief summary of what has been done in the past before proceeding to offer suggestions for the guidance of future effort.]

HISTORICAL.—Owing to the fact that the earlier observations of star colours were mostly confined to those of 'double' stars, any reference to past results must be more or less connected with the history of double stars in general. It is not necessary, however, to go farther back than the time of Sir W. Herschel, as he was undoubtedly the first great worker in this field of discovery. In addition to the now usual data relative to double stars, Herschel recorded their *colours*—an item not unfrequently ignored by some modern astronomers. But, from certain peculiarities of vision or of the instruments used, his estimates of colour differ materially from those of many subsequent observers. In 1837 appeared the 'Mensuræ Micrometricæ' of F. G. W. Struve, probably the most valuable contribution to double-star literature ever made, and which has served as a basis for all similar investigations since. The colours of the objects therein contained were noted with evident care, and may be considered as fairly accurate, though possibly Struve may have shown some lack of discrimination in the more delicate tints. In 1844 Admiral Smyth published his well-known 'Bedford Cycle,' in which considerable attention is paid to the colours of stars. Smyth appeared to have a keen sense of colour appreciation; indeed, it may be premised that he aimed at achieving more than was possible, in the case of minute *comites* to bright stars. Some obvious discrepancies in the colours of certain bright stars may be due to carelessness in recording them; a fault not uncommon in his micrometrical measures. A few years later Signor Sestini published some comparisons of star colours with those in the 'Cycle';

these were so obviously peculiar as to call forth a reply from Smyth in his 'Ædes Hartwellianæ' (1860), in which the result of a careful re-examination was confirmatory of his original work. Consequently, Sestini's colours did not find much favour with observers. In 1856 C. P. Smyth (the present Scottish Astronomer Royal) made his famous 'Teneriffe experiment,' when a large telescope was mounted on the Alta Vista at a height of 10,700 feet above sea-level. Some very interesting observations were there made, including those of double-star colours. The results did not greatly differ, with one striking exception (that of 95 Herculis), from those made by his father at Bedford, and therefore did not constitute very positive evidence as to the advantage of mountain observatories for this class of work. In 1864 Admiral Smyth published his 'Sidereal Chromatics,' which, besides much curious and interesting matter concerning star colours, contained a *chromatic scale* proposed as a standard of reference. Fig. 2 shows the plan of it—there being 4 shades of each colour, of which the deepest was called '1' and the palest '4.' But, notwithstanding this laudable attempt to overcome an acknowledged difficulty, the scheme was doomed to failure, because its pretty wafers of colour could not be directly compared with the glittering hue of a mere point of light. Following in Smyth's footsteps came the late Prebendary Webb, whose 'Celestial Objects' has probably done more to create an army of amateur telescopists than any similar work in the English language. Mr. Webb entered enthusiastically into the subject of star colours, and, choosing to depart from the beaten track, extended his scrutiny to many *single* stars, whose colours had been almost systematically neglected. Ruddy stars were also favourites with him on account of their rich hues; and he discovered not a few of

FIG. 2.—SMYTH'S CHROMATIC SCALE.



these interesting objects. By his advice the writer undertook an examination of the colours of all naked-eye stars visible in these latitudes during the years 1877–78, using a 5-inch refractor for the purpose. The total number of stars laid under scrutiny was 3,890, the majority of which have been included, in an abbreviated notation, in vol. xiv. part i. of the 'Annals of Harvard College Observatory.' In 1885–86 another survey was made, being partly a repetition of the former one, of 1,730 stars, but with the aid of a larger aperture—an 11¼-inch reflector. (A brief analysis of the results of each series will be found under the head of *Colour Distribution.*) The only prior observations of the colour of a great number of naked-eye stars are those by Sestini during 1844–46 with the 6¼-inch refractor of the Roman Observatory. He examined the colours of 2,540 stars from Baily's catalogue; but, judging by the tints he assigned to those doubles which were afterwards re-observed by Smyth, his results were affected by some idiosyncrasy which led to their rejection by contemporary observers. In what has been already mentioned, no reference was made to the southern heavens, and for the very obvious reason that there is practically nothing to record beyond the estimation of the colours of some of the brighter southern stars made by Colonel Tupman a few years ago. His paper on the 'Colours and Magnitudes of Southern Stars' will be found in vol. xxxiii. of the R.A.S. 'Monthly Notices.' Before closing this imperfect historical sketch, we must not omit to notice the names of Dawes and Knott in England, also Dembowski and Secchi in Italy, as assiduous observers of colour in connection with 'double' stars. Nor should we overlook some important experiments on the coloured components of doubles made by Professor Pickering with the help of an ingenious combination

of spectroscope and polarising photometer, and described in vol. xi. part i. of the Harvard 'Annals.'

PECULIARITIES OF STAR COLOURS.—Whilst among naked-eye stars may be found every known tint, from pure white, through various shades of yellow and orange, to orange-red, there is an almost entire absence of the colours belonging to the more refrangible part of the spectrum. A decided 'green,' 'blue,' or 'purple,' is nowhere met with, except among double stars; and we can scarcely resist the inference that the vivid hues so common in the smaller components of doubles are in some way, physically or optically, due to their association with a brighter neighbour. The best examples of such tints in isolated stars are probably Vega, which is bluish-white or very pale blue; and β Libræ, which may be called pale green or greenish-white. With double stars, when the components are unequal, and the larger star is not white, its colour usually inclines to the red end of spectrum, and the companion star tends toward the blue end. Some exceptions, of course, are to be found; such as 95 Herculis, where the primary is greenish, and the smaller star reddish. Two specimens of very peculiar tints may be cited. One is o^1 Cygni, and the other the *comes* of ζ Orionis: Struve described the latter by the euphonious term 'olivacea-subrubicunda'! The mean of several observations of each by the writer gave the respective tints as 'light bronze-green,' and 'olive-green.' A colour not at all uncommon in bright stars is a kind of citron tinge, more properly described as 'greenish-yellow.' It is somewhat curious that no example of a decided 'brown' tint was met with in over 10,000 observations of the colours of single and double stars. The nearest approach to it was perhaps 'cinnamon,' and this was very rare indeed.

A propos of peculiar tints, it may be mentioned that Smyth defined his 'creamy white' as pale white! His 'orange [4],' on his own chromatic scale, is almost exactly cream colour; practically equivalent to orange-white. It is certainly a matter for regret that so many vague and misleading terms have been imported into the nomenclature of star colours; especially those derived from such objects as flowers, fruit, or precious stones, of which probably no two are exactly alike. And, after all, many supposed discrepancies between various observers may be due to ambiguous modes of expression rather than to a real difference of perception. Such discordancies would be largely eliminated if some uniform and simple scale was agreed upon; using terms so definite as not to be easily misunderstood, and yet elastic enough to include the usual limit of errors of observation. (See section on *Hints for Future Work.*)

Red Stars.—Isolated stars of a ruddy tint are sufficiently numerous and important to constitute, by common consent, a distinct branch of observational astronomy. Nor is this surprising when we consider their remarkable aspect, the singularity of their spectra, and the fact that many of the 'variable' stars are included in the class. It may be noted, however, that all the *very* red stars are of telescopic magnitudes, there being no stronger tint than ruddy orange in naked-eye stars. The brightness of the image has probably some influence on its colour, as certain of the variables become paler in tint when near a *maximum*, but deepen towards a *minimum*. And the writer found that a number of stars which appeared ruddy with a 5-inch glass, proved to be merely orange when re-examined with 11¼-inch aperture. In 1874, Schjellerup published a complete catalogue of the red stars then known,

some 280 in number—being an extension and revision of his first list, made in 1866. This was further developed by Birmingham, whose 'Red Star Catalogue,' issued in 1877, included the observations of Schjellerup, Schmidt, Webb, &c., as well as those made by himself—the total number being about 650. A new edition of this work is now being prepared by Espin, which will bring our knowledge of these interesting objects up to a recent date.

VARIATION IN COLOUR.—It is perhaps an open question whether stars are subject to periodical changes of colour. Variability in brightness is of course well known, and it does not seem very unreasonable to infer that colour, inseparable as it is from light, may exhibit analogous fluctuations. Without pretending to offer a definite opinion on so controversial a point, some of the recorded evidence is here quoted.

(1) The case of Sirius will be tolerably familiar to most observers. It would appear that the ancients only recognised two colours among the stars—red and white. While their estimates of the colours of certain bright stars are fairly in accord with modern ones, that of Sirius forms a striking exception. Ptolemy, Seneca, and other ancient writers distinctly refer to Sirius as a *red* star; though now, as everybody knows, it is intensely *white*. Schjellerup, however, has recently discussed the evidence with regard to this star, and has arrived at the conclusion that the alleged change is very doubtful.

(2) The double star 95 Herculis had its components rated by Herschel, 1781, 'bluish white, white'; Struve, 1828, 'greenish yellow, reddish yellow'; Smyth, 1833, 1851, 1857, 'pale green, pale red.' This was the object that Piazzi Smyth found so discordant at Teneriffe, and he contended strongly for variation. His description was

'both greyish white,' at Guajara, 1856; but in Scotland, six years later, he made them 'yellowish, reddish yellow.' Sestini, 1844, called both 'gold yellow'; and Struve had also seen them so in 1832. The dates when the tints appeared alike are separated by twelve-year intervals—1832, 1844, 1856. Most subsequent observations, however, confirm the elder Smyth's results.

(3) λ Ophiuchi, another double, was recorded by Herschel, 1783, 'white, blue'; Struve, 1825, 'yellow, bluish'; Smyth, 1834, 'yellowish white, smalt blue'; Dawes, 1842, 'both white'—1848, 'pale yellow, greenish white,' 'pale yellow, deep yellow'; Espin, 1876, 'yellow, green'—1878, 'yellow, blue'; Fr., 1876, 'white, greenish yellow'—1878, 'pale yellow, blue'—1885, 'white, yellow.' The closeness of the components make this a difficult object for colour estimation.

(4) γ Leonis—Herschel, 1782, 'white, reddish white'; Struve, 1831, 'golden, greenish red'; Smyth, a little later, 'bright orange, greenish yellow'; Dawes, 1841, 'both orange'—1843, 'yellow, purplish yellow'—1848, 'yellow, greenish yellow'; Fr., 1878, 'rich yellow, paler ditto'—1885, 'yellow, flushed grey'—1887, 'yellow, purplish,' 'yellow, greenish.' The colour of the *comes* appears to fluctuate, the brighter star remaining constant.

(5) γ Delphini—Herschel, 1779, 'both white'; Struve, 1831, 'golden, bluish green'; Smyth, 1839, 'yellow, light emerald'; Sestini, 1844, 'orange, yellow'; Piazzi Smyth, 1856, 'cadmium yellow, greyish'; Gore, 1874, 'reddish yellow, greyish lilac'; Fr., 1879, 'yellow, greenish blue'—1884, 'yellow, greyish green.' The last four objects are noticeable as instances in which Herschel saw the stars *whiter* than other observers, contrary to his usual bias for red tints.

(6) 107 Aquarii—Smyth, 1832, 'white, blue'; Sestini, 1845, 'yellowish white, yellowish'; Smyth, 1850, 'white, purplish'; Piazzi Smyth, 1856, 'pale yellow, white'; Secchi, 1855, 'white, reddish blue'; Fr., 1885, 'white, lilac.'

(7) B 118 Orionis—Schjellerup, 1863, 'decided red'; Secchi, 1868, 'yellow'; Birmingham, 1876, 'blue'; Schjellerup, 1876, 'no longer red'; Fr., 1885, 'white.'

(8) B 169 Lyncis—Struve, 'red'; Secchi, 'fine yellow'; Birmingham, 1874, 'blue, or bluish white'; Greenwich obs., 1874, 'white.'

(9) B 447 Aquilæ—Schjellerup, 'red'; Birmingham, 1873, 'blue.'

(10) α Ursæ Majoris. Klein considers this star to pass through a series of colour changes, which Weber corroborates, and assigns a period of some 33 days. The alleged changes are from white, through various shades of yellow, to red; white occupying the longest interval and red the shortest. This result, however, is controverted by the great majority of observers.

(11) R Geminorum, a variable star discovered by Hind, was stated by him to pass though changes of blue, yellow, and red; which was apparently confirmed by Pogson.

(12) ο Ceti (*Mira*), the earliest known variable (discovered 1596), has been suspected of colour variation also. Sir J. Herschel (Cape obs.) called it 'very full ruby'; Schönfeld and Birmingham also described it as red. But Webb, 1878, found 'no trace of red'; and Flammarion 'less red than gas flame.' At two of its *minima* it was termed by Gore and Schmidt, respectively, 'fiery red,' and 'distinctly red yellow.' Some observations by the writer are—1876, 'orange red' (7 mag.); 1877,

'yellow' (3 mag.); 1884, 'decidedly red' (8 mag.); 1885, 'orange yellow' ($3\frac{1}{2}$ mag.). It will be noticed that the colour of this star deepens as its light wanes—a result which is in accordance with a fact elsewhere mentioned, that colour pales with great increase of light-grasping power in telescopes.

(13) *Nova* Cygni, 1876. This new star was first seen by Schmidt, Nov. 24, fully 3 mag., and golden yellow. It rapidly diminished in lustre, reaching 7 mag. by the middle of December; its colour gradually deepening as its light decreased, so that in January 1877 Dr. Copeland found it 'decided red.' Strangely enough, when re-examined at Dun Echt in September 1877—its mag. being then 10·5—it was termed 'faint blue.'

(14) *Nova* Andromedæ, 1885. The new star in the great nebula, discovered by Hartwig, August 31. At the outset its light was equal to $7\frac{1}{2}$ mag. and decidedly 'yellowish,' contrasting in a marked degree with the greenish tint of the nebula. But a month afterwards, when some two mags. fainter, its colour was as distinctly 'bluish'! This notable instance of colour variation was substantiated by many observers in this country, though, at the same time, the American observations exhibited strange discrepancies.

On carefully sifting the evidence for variation we are bound to admit that it does not constitute a strong case, and the verdict of most people will probably be 'not proven.' The most telling instances—those of the two *Novæ*—are open to the objection that they may not be, strictly speaking, 'stars' at all. And the apparent change in such an object as *Mira* Ceti is, we think, explained by the enormous difference in its brightness at *maximum* and *minimum*. The discrepancies in the tints of certain 'red'

stars may possibly be due to incorrect identification. This argument does not apply to the double stars; but where the components are tolerably close, it is at all times difficult to form an accurate estimate of colour, and a large margin must be allowed for errors of observation.

DISTRIBUTION OF COLOUR.—In analysing the results of certain spectroscopic observations, Secchi found about 300 stars of the first type, 200 of the second, and 30 of the third. White stars (type 1) predominated in Lyra, Ursa Major, Taurus (including the *Pleiades* and *Hyades*), and Orion. Yellow stars (type 2) prevailed in Cetus, Cepheus, Draco, Eridanus, &c. Webb has remarked the absence of colour in the Pleiades; and Pickering, from a photograph of their spectra, finds that nearly all the brighter stars in the group are of type 1. He further adds: 'It is very improbable that chance alone has brought together so many bright stars in the same portion of the heavens. Most of them probably have a common origin.' Birmingham found a certain part of the heavens between Aquila, Lyra, and Cygnus so rich in orange and ruddy stars that he denominated it 'the red region.' Sestini observed the colours of 2,540 stars, of which the 'yellow' stars were about half the total number, and equally distributed; the 'white' stars one-fifth, in scattered portions; and the 'orange' rather more than one-fifth—this is sufficient indication of his bias toward yellow tints. Guillemin, on the contrary, says that 'white' is undoubtedly the colour of the great majority of stars. Struve, out of 476 pairs of similar colours, found 295 white, 118 yellowish, and 63 bluish. In dealing with colour distribution from a spectroscopic point of view, it may be remarked that some difference of opinion exists as to the mutual relation between the spectrum of a star and its colour; which is

sometimes said to be close, and, again, that there is but little affinity. Secchi stated that 'the naked-eye colour of a star may not indicate the superior development of that colour in its spectrum.' Maunder, however, maintains that 'the colour of a star is exactly and minutely correspondent to the typical character of its spectrum'; and adds that 'a very fair guess may be made at the width, blackness, and definition of the F line from the inspection of the colour of a star previously unknown'—this opinion being based on the observations at Greenwich of the spectra of stars down to the 4th mag. The spectrum of a star should undoubtedly be a valuable check on the eye estimate of its colour, though, as white light may be produced by different combinations of colour, the dual results may sometimes differ. The discussion of star magnitudes derived from photographic charts affords an additional criterion of the accuracy of eye observations of colour; since by comparing the actinic and visual magnitudes together we find that large residual differences are caused by extremes of colour. 'Blue' stars have a greater effect on the sensitised plate than on the retina of the eye; whilst the converse is true of 'red' stars. Espin gives an approximation as to the effect of colour on photographic magnitudes, as follows:

Red . .	+2·5;	orange-yellow	+1·3;	white . .	−0·0
Orange-red	+1·9;	yellow . . .	+0·8;	bluish white	−0·5
Orange .	+1·6;	yellowish white	+0·4;	blue . .	−1·6

Thus, white being taken as unity, of three stars equally bright to the eye, their colours 'red,' 'white,' and 'blue,' respectively, the red star would come out 2½ magnitudes *less*, and the blue 1½ magnitudes *greater* than the white one, on a photograph. A knowledge of this fact has already led to the detection of several new 'red' stars; and, pos-

sibly, the future discovery of such objects will largely depend on this method. A brief analysis of observations made by the writer in 1877–78 and 1884–86 gives the following results with respect to colour distribution:

	White	Yellow	Orange	Red	Total
1877–78	1,753	1,456	607	34	3,850 stars
1884–86	962	614	168	10	1,754 „

Percentages.

	White	Yellow	Orange	
1877–78	46·0	38·1	15·9	from 3,816 stars
1884–86	55·2	35·2	9·6	„ 1,744 „

Many different terms were used in describing the tints, but these were merged in the broad divisions of white, yellow, and orange, in order to arrive at some idea of their relative proportion.

The ruddy stars do not, in either series, amount to ·2 per cent. of the whole number. Nor is any account taken of greenish or bluish stars in this classification; being comparatively rare, they were included under 'white' stars. It will be noticed that there is a systematic difference between the two series; arising, no doubt, from the different telescopes used—a 5-inch refractor in 1877–78, and an 11¼-inch reflector in 1884–86. The larger aperture generally made the tints appear *paler*; which seems to point to the conclusion that the colour of stellar light is affected to some extent by its intrinsic brightness. Notwithstanding this relative difference between the two sets of observations, the results from each series are fairly accordant, and a discussion of them brings to light some curious facts. The possibility of arriving at some generalisation is important, as a step towards more accurate knowledge of the structure of the stellar universe.

With due allowance for the imperfect materials to

hand, on which to base general deductions, the following inferences are believed to be approximately correct: (1) Colour is *not* uniformly distributed in the heavens, but tends to group in certain regions. (2) Those constellations having many *bright* stars are, as a rule, remarkable for their high percentage of 'white.' (3) In constellations having many *small* stars, and relatively few bright ones, the 'yellow' and 'orange' tints are most abundantly found. (4) Most of the constellations with a large percentage of 'white' stars are associated with the Galaxy—e.g. Cassiopeia, Perseus, Taurus, Orion, Scorpio, Lyra, &c. The yellow and orange coloured stars are most plentiful in large straggling constellations, such as Cetus, Pisces, Hydra, Leo, Virgo, Boötes, Aquila, &c.; whilst the rich compact asterisms are distinguished for their number of white stars. The most striking aggregations of colour in the heavens are probably to be found in Taurus and Orion for 'white' stars, and in Cetus and Pisces for 'yellow' stars; which is also borne out by Secchi's spectroscopic observations.

Errors affecting Colour Observations.—These will be considered under three headings—those arising from the atmosphere, the instrument, and the eye of the observer. The first is ever varying, the second may be assumed as constant, whilst the third is probably subject to unknown fluctuations. It is not unlikely, though, that the nature of these various errors may be such as to partly neutralise each other.

Atmospheric.—The aërial envelope surrounding our earth must exert some influence on the rays of light which pass through it from the heavenly bodies. What may be the absolute amount of absorption—general or selective—it is impossible to say, as we can only judge of its relative effect

from the zenith to the horizon, and this only affects the lower strata. But, on account of the rapidly diminishing density of the air as we ascend from the surface of the Earth, which at 18,000 feet elevation is only one-half of its total mass, it is evident that the effect of the highly attenuated upper atmosphere must be comparatively insignificant. So far, the exact nature and extent of atmospheric influence on colour is very imperfectly understood; and until the effect of its absorption on rays of different refrangibility, under varied hygrometric conditions, is made the subject of rigid investigation, it will be hopeless to apply empirical corrections for such errors. The present method of observation is therefore liable to errors which are not systematic, but irregular. As a general rule, the effect of the atmosphere is to reduce the colour to a less refrangible hue as we approach the horizon, though how far this may be modified by other circumstances it is hard to say. (The writer has noticed a remarkable difference in the colours of stars within some 7° of the horizon, as viewed in dry frosty air, and immediately after heavy rain.) The reddening effect upon the Sun or Moon when near the horizon is familiar to everybody; but even this is not perfectly regular, depending to some extent on the hygrometric conditions. Stars must be similarly influenced; and, moreover, on account of their light being concentrated nearly to a point, the dispersive action of the atmosphere is rendered very apparent. It will thus be seen that colour observations at low altitudes are untrustworthy, and should be avoided; unless, indeed, the study of atmospheric effects be the object in view.[1] An elevation of 20° above the horizon is

[1] A prolonged series of observations on such stars as Capella and Vega might yield some valuable evidence respecting atmospheric absorption.

about the minimum limit than can be safely recommended. It is, of course, preferable that *all* colour observations be made near the meridian, to minimise atmospheric disturbances as far as possible. Haze and fog, unless very slight, are generally serious obstacles to the accurate estimation of colour, though admirably suited to the splitting of close double stars. If the components of coloured pairs are sufficiently bright, it sometimes happens that the prevalence of a little mist or haze will, so to speak, accentuate their colours. This may be through the difficulty, at other times, of judging the exact relative tints of two bright objects in close proximity. Some double stars are, as is well known, more susceptible than others to atmospheric influence, and a closer study of such test objects might lead to valuable results. The illumination of the background on which the stars are seen, as well as the colour of the sky itself, are matters not to be neglected. The effect of moonlight on the colours of stars is probably small, though still perceptible; but twilight exerts a much greater influence. Both act in a similar way, by shifting the colour slightly towards the less refrangible end of the spectrum, and thus it is that many stars appear *yellower* in twilight than on a dark sky. Daylight observations are subject to the additional error introduced by the blueness of the sky, which must bias the eye somewhat towards a complementary tint. What is usually called 'definition' of telescopic objects is of course mainly a function of the atmosphere; that is, assuming no imperfection in the instrument. It is, we suppose, a current belief that this is of no consequence as applied to colour observations. But, *cæteris paribus*, what is good for stellar observations in general must include colour observations as a necessary part of them. Common-sense would argue that colours are best

seen when definition is best, and this is practically found to be the case. Flaring definition or vivid scintillation is generally accompanied by blurred and uncertain colours.

Instrumental.—The errors due to the instruments employed in colour investigations are the least serious of any, because they are constant and can be readily allowed for. Between the exquisitely perfect specimens of modern optical art, whether reflectors or refractors, there is probably no appreciable divergence in results, when the comparison is limited to *moderate* apertures. But it is otherwise when we come to *very large* refracting telescopes, such as are now common in many observatories. Owing to the irrationality of dispersion of its two lenses, the most perfectly corrected object-glass must have a certain amount of residual colour. This, though scarcely noticeable with small lenses, increases almost in proportion to the square of the aperture; so that in very large glasses it forms a painfully obtrusive blue halo round the image of a bright star. Such great refractors are clearly unsuitable for delicate appreciation of star colours. The silvered specula of reflecting telescopes are fortunately free from this defect; though, theoretically, they do absorb some of the more refrangible rays of light, as may be demonstrated by looking at the Sun *through* the silver film, which will then appear 'blue.' This means that they must slightly redden objects viewed with them; practically, however, this effect is almost imperceptible. On the whole, therefore, we give the preference to reflectors for colour work; and, as usually made of the Newtonian form, they are delightfully easy to use in positions which are most awkward with refractors, near the zenith. And it cannot be too strongly impressed that, if the eye is to do its best, the body must be in an easy, uncramped position. The use of a diagonal eyepiece

will, it is true, remove this objection to the refractor; but the total reflection prism is not to be trusted for crucial definition, neither is it free from accidental colour. Metallic reflectors are, happily, now discarded in favour of silvered glass: their reddening effect was very marked indeed. And very old object-glasses, with their greenish crown lenses and imperfectly polished surfaces, are not likely to be often met with; though it is as well to warn the amateur against using antiquated instruments. Nor are modern object-glasses to be chosen indiscriminately, even if reputed good. The writer has met with such surprising variation, as regards colour correction, in the work of the best makers, that he feels impelled to utter this caution. If properly corrected, a pale green fringe is seen outside the focal point, and a purple fringe within. At the focal point, with a moderate aperture, a bright star like *Vega* should show but a trace of deep blue (nearly violet) round its image; if there is a considerable fringe of vivid blue the object-glass should be rejected as unfit for colour observations. A rather important factor in estimating star colours is the *aperture* of the telescope used; as a matter of experience it may be stated that many stars appear *paler* in colour as the aperture is increased. (See also a footnote on p. 209, 'Celestial Objects.')

A source of error, which may be considered instrumental, lies in the *artificial light* by which the observations are recorded. If oil or gas it is sure to be yellowish, and this cannot but be prejudicial to the eye, when attempting such delicate work as the precise definition of colour. The incandescent electric lamp is, *par excellence*, the illuminant to employ, wherever possible to do so: otherwise a hand-lamp which burns petroleum is about the best substitute. Whatever the light used, it should not be

stronger than is absolutely necessary for the purpose, and the eye must be protected from any direct glare. A soft diffused light is the thing to be aimed at, and a little ingenuity will soon accomplish this with any kind of lamp.

Personal.—The eye of the observer is perhaps the most important factor in determinations of colour, and possibly the least taken into account; for in no other branch of astronomical work do we find such discrepancies as are exhibited in the tints assigned to stars by various observers. Although there is undoubtedly a systematic difference between one person and another in the perception of colour, which corresponds to a displacement of hues either to a more or less refrangible position than the normal, yet this 'personal colour equation' cannot be said to remain constant. There is no doubt whatever as to variation in sensitiveness of the same eye at different times;[1] and, considering the intimate connection of colour with brightness, it is not unlikely that the constant of colour will be sometimes exaggerated and sometimes diminished thereby. It is very difficult to form a correct judgment of colour in lights of greatly dissimilar intensity, and few persons would use the same term in describing the colours of a 1st and a 6th mag. star, even though they were actually alike. It is interesting to compare the colour observations of different astronomers, as bearing on the question of personal equation. Herschel as before mentioned, was partial to red tints; and Struve from an elaborate collation of such estimates with his own came to the conclusion that the differences were chiefly due to the metallic reflectors used by Herschel. This explanation does not account for the several instances in which Herschel saw the objects *whiter* than Struve,

[1] It certainly varies, to some extent, with the condition of the nervous system and the general state of the observer's health.

unless we admit the theory of real variation in their colours. A subsequent comparison of colours observed by Struve and Secchi, both using refractors, seemed to show that the latter had a bias for yellow tints. The same tendency was manifested by Sestini, whose colour results were so evidently affected by some idiosyncrasy that they found but little favour with other observers. Schmidt, too, appeared to be troubled with a preference for red tints, as his observations of so-called 'red' stars pretty clearly proved. Littrow, it is commonly reported, could not distinguish between the colours of Antares and Vega—probably a genuine case of 'colour blindness!' The most eminent observers of double stars do not seem to have been as good at colour work as they were skilful with the micrometer. And those persons who possess remarkable acuteness of vision seldom have a perfect colour appreciation. With regard to *colour blindness* a good deal of misconception appears to prevail. In such cases as have been carefully investigated the so-called 'blindness' consists in the absence of the elementary sensation corresponding to red; that colour appearing to them as a kind of dark neutral tint. Instead of three primary colour sensations, they have only two; this peculiar affection is therefore more properly termed 'dichroic' vision. It is thus scarcely necessary either to consult an oculist (as suggested by one observer) or to employ any complicated apparatus in order to determine this point; five minutes' use of a spectroscope will enable any one to settle it for himself. Many supposed cases of colour blindness arise from defective education of the colour sense, or want of judgment in naming certain tints. At a meeting of the American Academy of Sciences (May 1886) Professor Ogden N. Rood described some experiments on colour contrast, from which it seems 'that

colours appearing on neutral ground to the naked eye, as a result of contrast with those seen, are not, as is generally supposed, complementary, except in the case of red; and in proportion as the violet end of the spectrum is approached so do the contrasted colours differ more and more from the complementary ones.' He found also that bluish colours affect the eye more than reddish ones (this seems contrary to photographic evidence, though), but the reason of these physiological actions he was unable to explain. Colours do certainly differ somewhat according to the background on which they are viewed, whether white, black, or neutral; and any colour discs used for comparison with stars ought to be on a *black* ground. In the conflicting estimates of different observers part of the error, it has been suggested, may be due to too rapid work, in not giving the eye sufficient time to eliminate the effect of the complementary tint to that colour on which it last rested. This may be so in some cases, but we think greater discrepancies are due to the illumination of the micrometer wires, and the light used in reading circles—where the colours of double stars are concerned. As the result of a considerable experience, we find that the first good look at a star's colour is generally the best one, and least likely to be biassed; prolonged scrutiny wearies the eye, and then perhaps quite a different tint is assigned.

Hints for Future Work.—It will be obvious, after what has previously been said, that our knowledge respecting the colours of stars is, at present, very incomplete and unsatisfactory. To do something towards remedying this deficiency might well excite the enthusiasm of the amateur; and, with this end in view, we venture to throw out a few hints for his guidance. In estimating star colours, probably the first difficulty arises from the want of something

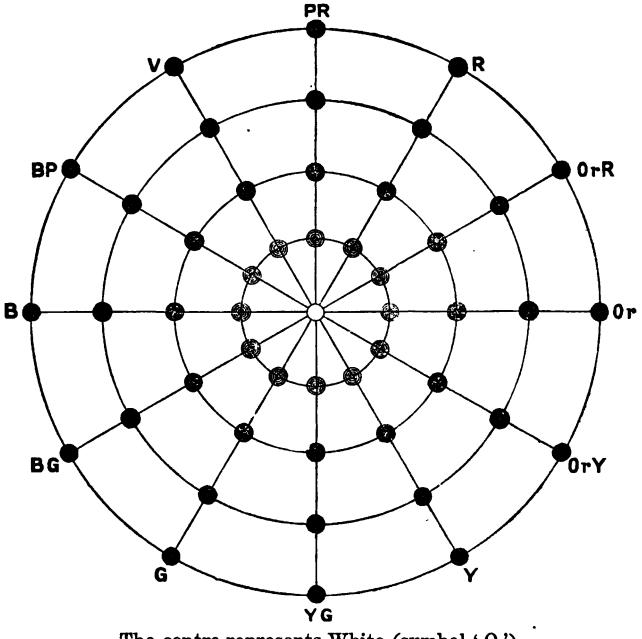
to compare them with—a kind of *artificial scale*, in fact, by which they can be matched. This desideratum has long been felt, and several attempts have been made to supply it. Smyth's 'chromatic scale' has already been described, and the cause of its failure alluded to. A coloured plate in C. P. Smyth's 'Madeira Spectroscopic' is intended for a similar purpose. It is arranged on spectrum principles, with a graduated series of primary, secondary, and tertiary tints. But, of course, the same objection will apply to this as to its predecessor—that it cannot be directly compared with a star. Hopkins has proposed that a standard scale of colours be executed in mosaic, on account of the permanence of the tints so prepared; but it is not easy to see how this can be of real service as applied to the determination of star colours. The foregoing plans fail on account of the incomparableness of light with any opaque colour viewed by reflection. A better method consists in using transparent films of colour, illuminated by some artificial source of light placed on the further side. Such is essentially the principle of Hopkins's 'Astro-chromoscope' (*English Mechanic*, vol. xxxiv. p. 112), and Ballot's 'Chromometer' (*English Mechanic*, vol. xlii. p. 493, and vol. xliii. p. 57). Both these instruments produce an 'artificial star' in the field of view, suitably coloured by means of stained glasses mounted on revolving discs. The latter arrangement (Ballot's) is indeed most elaborate, as it contains no less than 28 tints (on four discs of seven colours), and each of these tinted shades is in the form of a wedge; so that the brightness as well as the colour can be made to match the real star. But the apparatus suffers from over-complication, and would be very expensive to construct. There are grave objections, however, to the use of all *artificial* standards of compari-

son; the most salient being that they do not vary with atmospheric conditions, as the stars themselves must do. It is questionable, too, whether the artificial star can be so nicely adjusted as to exactly coincide with the brightness of real stars which differ much in magnitude. Moreover, a fresh series of errors would be introduced by the instrument, the extent of which would have to be determined before its results could be implicitly accepted. Undoubtedly the best standards are the stars themselves; but at present their colours cannot be compared *inter se* with any great amount of precision. What is wanted, in order to practically realise this idea, is some kind of instrument that shall bring the comparison stars into the same field of view; and then *relative* estimates of colour could be easily and accurately made. This suggestion, however, scarcely meets the difficulty of how the *absolute* colours of the comparison stars (preferably circumpolar ones) are to be ascertained.

Another impediment to colour observations is due to the fact that hitherto no uniform system of *nomenclature* has been adopted. The fanciful names used by Smyth and others were largely borrowed from the supposed hues of flowers, fruits, precious stones, and the like—of which probably no two are precisely similar. Many discrepancies can be traced to this source, and it is high time such vague and arbitrary terms were finally abandoned. Any system of nomenclature that aims at being an improvement ought to possess the following requisites: (1) Its basis should be the solar spectrum, and its fundamental terms directly referable thereto. (2) Its notation should be clear and precise, yet simple and easily remembered. (3) Its terms should be capable of numerical expression, so as to admit of reduction to mean results. The writer believes

that the scheme herewith presented will satisfy these conditions. Its inception was due to a suggestion by Professor Pickering that each colour should be expressed by a series of numerically progressive terms, placing white at

FIG. 3.—CHART OF STAR COLOUR NOMENCLATURE.



The centre represents White (symbol 'O.')

one end of the scale. It was then seen that by making white the common zero, and the numerical terms correspond to direct increments of colour, such a plan as that shown by Fig. 3 could be readily arranged. The unit of this system of notation is 'white,' represented by the

symbol 'O.' Any departure from white must necessarily be in the direction of some prismatic colour; hence white is made the common centre from which various tints radiate—such tints following their spectrum order. The colour on any radius deepens, by four successive steps, as it recedes from the centre, and is thus numerically expressed. The innermost circle means white *just tinged* with the colour; the next outer one a *pale* shade of the colour; the next corresponds to the *normal* colour; and the outermost a *deep* shade of the colour. The colours advance in the same order as the hands of a clock, beginning with red (R) and ending with violet (V); the extremes of the spectrum being connected by the intermediate purplish red (PR). There are six chief colours—red, orange, yellow, green, blue, violet; and six subordinate tints—orange red, orange yellow, yellowish green, bluish green, bluish purple, purplish red. Their symbols are shown on the diagram; and the figure 1, 2, 3, or 4 placed to the right of the symbol denotes the approximate depth of shade. The subordinate tints are compounded, in fact and in name, of their adjacent primaries; except the terms 'bluish purple' and 'purplish red'—the strict equivalents of 'bluish violet' and 'violet red' not being so well recognised by most persons. With regard to the standard of the chief colours, the spectrum place of their centres is assumed to be that given by C. P. Smyth ('Madeira Spectroscopic'), as follows:—

	Central wave number	Nearest solar lines
Red	36,000	a and B
Orange	40,000	α (alpha)
Yellow	43,000	D^1 and D^2
Green	49,000	b^1, b^2, &c.
Blue	56,000	d
Violet	60,000	G and g.

Smyth's chromatic scale contains 24 tints; the present one 49 (including white). And the sequence of his numbered terms runs in *inverse* ratio to the depth of shade; whereas in this scheme they are *directly* proportional, or intended to be so. A complete list of the terms and their symbols is here given:—

GRADE 1.

Very pale tint.

	Symbol
Ruddy white	R^1
(Cinnamon) white	OrR^1
Creamy ,,	Or^1
(Chrome) ,,	OrY^1
Yellowish ,,	Y^1
(Olive) ,,	YG^1
Greenish ,,	G^1
(Glaucous) ,,	BG^1
Bluish ,,	B^1
(Purplish) ,,	BP^1
Lilac ,,	V^1
(Pinkish) ,,	PR^1

GRADE 2.

Pale tint.

Pale red	R^2
,, orange red	OrR^2
,, orange	Or^2
,, orange yellow	OrY^2
,, yellow	Y^2
,, yellowish green	YG^2
,, green	G^2
,, bluish green	BG^2
,, blue	B^2
,, bluish purple	BP^2
,, violet	V^2
,, purplish red	PR^2

GRADE 3.

Normal tint.

	Symbol
Red	R^3
Orange red	OrR^3
Orange	Or^3
Orange yellow	OrY^3
Yellow	Y^3
Yellowish green	YG^3
Green	G^3
Bluish green	BG^3
Blue	B^3
Bluish purple	BP^3
Violet	V^3
Purplish red	PR^3

GRADE 4.

Deep tint.

Very red	R^4
,, orange red	OrR^4
,, orange	Or^4
,, orange yellow	OrY^4
,, yellow	Y^4
,, yellowish green	YG^4
,, green	G^4
,, bluish green	BG^4
,, blue	B^4
,, bluish purple	BP^4
,, violet	V^4
,, purplish red	PR^4

There is a peculiarity of aspect belonging to some stars, over and above the colour itself, which may not inaptly be likened to *timbre* in music. And there are tints so extraordinary that no regular notation could adequately define them—such as that of o^1 Cygni, for example. In either of these cases the normal designation of colour should be supplemented by descriptive remarks; although, as the former is something apart from colour, it scarcely comes within the scope of such investigations. Then, again, we have the modification of hue which is entirely a function of brightness; as in the transition from the dazzling splendour of Sirius down to the soft silvery light of a small star. It is not claimed for the proposed system of nomenclature that it shall provide for extraordinary cases, which are relatively few and far between; but it does afford a convenient and definite notation by which the colours of the great majority of stars can be expressed without much ambiguity.

As the method of careful *eye-estimation* (with improved nomenclature) is likely to be the one most in vogue with amateurs, so it will be best to restrict the concluding remarks to this, with such hints as may be found of service. The colours of the *brighter* stars (especially circumpolar ones) ought, in the first place, to be determined with what exactness is attainable as the mean result of many independent estimates. It would be advisable to commence with stars from 1 to 4 magnitude, and make a number of observations of each, with intervals of several days between. The differences arising from moonlight and varied atmospheric conditions will thus be manifested. With an equatorial mounting the colours of very bright stars may be observed in twilight, as an additional variety in the results. And of course the state of the sky during

each series of observations should be recorded—whether moonlight, twilight, clear, hazy, calm or windy—as also the character of the definition. As to the number of objects that can be well observed on each occasion, much depends on the time that can be afforded; probably twenty or thirty will be sufficient for an average evening's work. It cannot be too strongly impressed, however, that it is better to do a few well than to hurry over a large number. As before hinted, avoid exposing the eyes to artificial light as far as possible, when making colour estimates; most artificial sources of light having a decidedly yellow tone, and a strong light also causes the iris of the eye to contract. Some one has recommended that one eye be used for the telescope, and the other for writing down; but if one eye is violently affected it will cause a sympathetic action in the other. The writer finds that with his right eye stars are perceptibly brighter than with the left (which is generally used for the telescope), but not so well defined; neither is the colour perception equal in both. Stars that are near the limit of visibility should never be observed for colour; with moderate apertures the tints of stars below the 8th mag. are usually obscure and ill-defined. And carefully eschew the colours of such objects as are within 15° or 20° of the horizon, because the results are certain to be vitiated by atmospheric effects. Haze and fog are, in general, also to be avoided. When sufficient observations have accumulated, those of each star should be collated, and, if fairly accordant, the mean of them may be adopted as the registered colour at the mean epoch of observation. If, however, striking discrepancies are met with in any of them, such objects should be selected for a more prolonged series of observations; by this means probably some interesting cases of colour variation will be

brought to light. To eliminate the effect of personal equation, it would be better if several observers agreed to examine the objects simultaneously (as far as possible), and the mean results of each combined to give the final value. Such stars, whose colours were thus determined, might then well serve as *standards*, wherewith to extend the survey to lower magnitudes. The colour of *every* star down to eighth magnitude ought ultimately to be obtained; though it is feared that the process of recording them will be a slow one. The discrepancies arising from *instrumental* peculiarities have already been noticed, and the observer will do well to bear these in mind. The silvered-glass reflector seems, on the whole, best suited for colour observations; but the choice of a suitable 'eyepiece' is also a matter of some importance. It should be as achromatic as possible, and have a tolerably large as well as a flat field. (The 'Kellner' and 'Aplanatic' can, from experience, be safely recommended.) The magnifying power need not be high; probably from 80 to 120 is as useful as any, for the examination of isolated stars. For double stars a greater amplification is often necessary; and, in examining these, an *occulting bar* is advantageous, so that the colour of each component can be separately estimated. The colour of a small star must be influenced by the immediate proximity to a very bright one; and it is curious to notice how a star's colour is affected by the presence of a large planet in the field, which of course is merely a subjective phenomenon. The star should be kept in the *centre* of the field whilst its colour is being observed, as the margin is never perfectly achromatic. Sometimes it is as well to put the star slightly out of focus, in order to get a better idea of its colour; but this 'wrinkle' is not recommended with *refracting* telescopes, unless of small aperture. It is

hoped that amateurs will attack the subject of stellar chromatics with their accustomed zeal and energy, so that this much-neglected department of observational astronomy may emerge from the obscure mists of its early environment and take its proper place with other branches of scientific knowledge. In conclusion, the writer wishes to express his indebtedness to several observers for their valuable suggestions and advice during the preparation of the foregoing chapter—the acknowledgment of which would not be complete without mentioning the names of Pickering, Maunder, Westwood Oliver, Hopkins, Gemmill, and Woodside.

W. S. F.

CHAPTER X.

STELLAR DISTRIBUTION.

THIS subject is one of the most difficult in Astronomy, and its study has therefore not been so generally undertaken as that of many other branches, although it is the one which is the most calculated to impress us with the greatness of the Creator and the extensiveness of His works. The first observer who examined into the subject to any great extent was Sir William Herschel; and Mr. R. A. Proctor is the chief living authority on it.

It was long believed that the nebulæ and many of the clusters are far beyond the Galaxy, or Milky Way; and that indeed they form other galaxies, perhaps similar to the one that encircles our skies. Mr. Proctor has shown that this is unlikely, and that most if not all these probably form but one system with the Galaxy ('The Universe,' p. 42, &c.)

The distances of but few of the stars are known yet; and, as Proctor has demonstrated, they vary exceedingly in size, and therefore we can judge but little of their distance by their brightness. Professor Gould has made investigations into stellar distribution, chiefly as regards those stars visible to the naked eye, and he holds that our Sun is one of a group of about 400 stars, the Milky Way lying outside such group (see 'Uranometria Argentina,' p. 364).

Apart from the existence of clusters, the stars are not arranged haphazard in the sky, and it is evident there must be certain laws of distribution. It has long been recognised that double and triple stars are far more numerous than they would be if they were scattered by chance; and that a large proportion of these do not consist of stars merely optically near, and separated by wide distances in reality, but that they are physically connected, in which case they are called binary and ternary stars. Besides this, they are very apt to lie in streams or lines; and Proctor has shown (see 'The Universe,' article 'Star-drift'), by charting their proper motions, that there are certain regions of the sky where there is a general drift of the stars in certain directions.

If our Sun is one of a cluster of stars, it yet remains to be examined what its motion is relatively to the others of the cluster; whether it is travelling alone, or together with other stars—few or many—in that cluster; and what the motion of the cluster is relatively to the stars of the Milky Way.

The Milky Way is known to be composed, at least mainly, of stars, i.e. of suns, though it may be very small ones. When it is carefully observed with the naked eye it will be seen how extremely irregular and complex its structure is. The diversity between drawings of the Milky Way is very great; it does not, however, follow that any are wrong, but it is probable that most if not all the features drawn in different maps really exist. It is unlikely for two persons' eyes to see the Milky Way exactly similar, one feature striking one's eyes, and a different one the other's; but it is difficult to speak with certainty on this point, as probably no attempt has ever been made to draw all the features visible with the naked eye. Marth has

given calculations for aid in drawing it (*Monthly Notices* of the Royal Astronomical Society, vol. xxxiii. pp. 1 and 517, and vol. xxxiv. p. 77).

[In delineating the Galaxy, I have found the best plan to be to make a tracing of the stars of the region to be observed, prick off copies, and ink the stars in on these. The Galaxy can then be drawn in pencil. It is not, as some imagine, in any sense a *continuous* stream, but a vast assemblage of clouds, streams, films, flecks, and sprays of light. This fact must be borne in mind, both in delineating and describing it; and it must further be borne in mind that the greater part of the importance of the study, of the form and structure of the Milky Way, lies in the investigation of these details, and not in the description of its general course—which is well enough known. Another fact important to remember is that, besides the brighter main stream, there lie on either side what may be called *faint extensions* of milky light. These extensions—*wings*, in some cases, they might almost be called—are not always, by any means, equally visible, but require very fine air for their proper observation. I have little doubt that one of the main causes of the discrepancies between existing accounts of the Galaxy is, that some observers have considered the brighter streams alone as constituting it, while others have included in it these wide extensions of misty light on either side. Notably does this appear to be the case with the descriptions and delineations of J. Herschel and of Heis respectively. These faint extensions—some of which stretch far—are well worth scrutiny. Another feature of the Galaxy which should be observed is the *rifts* it exhibits. There are a number of these, and they lie in all directions—lengthwise, diagonally, and transversely. The most remarkable is that near ρ Cygni—which is,

strange to say, not shown by Heis. The estimation of the 'magnitude' of different portions of the Way is a difficult matter, and the difficulty is increased by two circumstances. The first is, that it is not easy, in some cases it is impossible, to have in sight at once a sufficient number of portions of varying brightness to serve as standards of comparison. The very varying altitude of differing portions of the Way at those times when it is best situated for observation is likewise an impediment, as atmospheric absorption is introduced, and may cause very serious errors in the results, if higher and lower regions be compared. The second of the circumstances alluded to is, that the presence of the brighter stars upon the Galaxy renders the estimation of the neighbouring portions pretty difficult. Indeed, when the air is damp, the diffused light round the brighter stars sometimes makes the scrutiny of the neighbouring detail puzzling, by blurring it. As to general observation, it may be noted that observations should always be made with the naked eye, and without optical assistance from telescope or opera-glass. Further, if care be taken to take advantage of opportunities, many occasions will be found for observing the structure of the Galaxy. Some write as if the Galaxy could only be studied properly in southern regions or at very high altitudes. In point of fact, it is difficult to put a limit to the detail discernible in the Galaxy in clear air. The best views I have had of it have generally been in the breaks between showers, in the spaces separating heavy clouds drifting before a light wind. A still, dark night, following upon a windy and showery day, affords sometimes the best opportunities. But it is certain that the opportunities will be found—if watched for.[1]—S. M. B. GEMMILL.]

[1] The following is an extract from my observing-books: 'December 2, 1885. 9 hours. Air very transparent, but sky "light."

The spectroscope has shown us that many of the nebulæ are masses of incandescent gas. Others may be closely-set clusters of stars. On this subject Mr. Proctor has the following (*Knowledge*, vol. vii. p. 42): 'The mere visibility of milky nebulosity in the star-depths tells something about the distribution and nature of the stars within the region observed. Stars separated by considerable distances can never appear like a diffused cloud. Stars of the same

The milky extensions on either side of main stream were very apparent. They extend very widely, and especially upon the northern side of the main stream. The complexity of the Galaxy, both in the main stream and in the extensions, and differences in brightness between different parts, were very apparent. Between the tail of Cygnus and the head of Cepheus the *northern* edge of the main stream is very well defined, much more so than the southern edge. The "extension" which lies north from the Great Cloud stretching between β and γ Cygni crosses Lyra. It did not, to-night, seem to include Vega: it trends farther to the right, but seems to cease at 16 Lyræ. α, γ, ν, Cygni bound a wide triangular space, almost, if not quite, devoid of milky light; but there is a band of light from α to γ Cygni concave to *south*, and extending northwards. The "extension" that passes from α Cygni towards o, reaches ι. It extends so far as to include, I think, 39 Draconis, and almost include π Draconis; and it bends round and seems to take in θ Cephei. The whole area is strangely mottled. The black oval space near α Cygni was very evident. It is not well defined, but is very dark, by reason of contrast. The dark space near δ Cephei was also very evident. The rift near ρ Cygni was conspicuous; the bright cloud has for its boundary the curve of stars beginning with α and passing through ξ Cygni. The line joining α and β Cephei marks the boundary at that point. The line following the curve of stars connecting β Cephei with γ Cephei marks the boundary of the more obvious Galactic lights here. But at or about a naked-eye star (this star I afterwards identified from the "Harvard Photometry" as B.A.C. 7881) and marked 5 mag. in Proctor's *Atlas* in R.A. xxii. $30^m \pm$, Dec. $75° 30' \pm$ *north*, a curve seems to go off towards the Pole, and it seems to extend a considerable way towards it. There is a dark space *preceding* β Cassiopeiæ.'

size, but somewhat more closely set, will appear as a very faint nebulosity if far enough away; if still more closely set, such stars will appear as a brighter nebulosity, even when at a more moderate distance; and a number of such stars very closely set indeed will appear as a very bright nebulosity even at a small (relative) distance. But wheresoever set beyond the distance at which nebulosity results, a star-cluster will appear neither brighter nor fainter, only larger when nearer, and smaller when farther away.

'Thus when we see a bright milky nebulosity in a rounded region (the shape showing that we have not to do with enormously long ranges of stars in the direction of the line of sight), we know that we have before us closely-set stars, not stars strewn like those which form our constellations. We know that the stars in Cassiopeia, for instance, could never form a nebulous group such as the Pleiades appears to weak eyesight, or the beautiful cluster in the sword-hand of Perseus to the keenest vision. For we know that long before the stars in Cassiopeia had approached near enough to each other—through the recession of the group—to coalesce, they would have disappeared wholly from view. Nor would any further increase of distance and the use of the telescope make any difference; the telescope would increase the brightness of the stars themselves as it increased the apparent distance between them; and at whatever distance the stars disappeared to telescopic vision, they would still be as far from coalescing as when similarly disappearing to ordinary vision. (Perhaps I should rather say to ordinary vision corrected by a glass just making the stars neat and well defined; for there is not one man in a thousand whose view of a star-group is not to some degree improved by the use of an eye-glass just adapted to correct the defects of

vision—defects scarcely noticeable otherwise.) So that the group of stars forming the Pleiades is altogether differently arranged from the group of as many stars forming Cassiopeia; the group forming the Beehive (Præsepe in Cancer) is again differently arranged, the group in Perseus differently arranged still; and in fine each star-grouping is unlike its fellows, just as the family of giant planets is unlike the family of terrestrial planets, and that family again unlike the zone of asteriods. The arrangements of stars are as varied as are the stars themselves unlike in size and glory; the architecture of the stellar universe is as diverse as its materials.'

It follows that nebulæ, whether resolvable or not, are of a totally different character from groups of stars such as that of which our Sun is a member; and that they may be no further off us than the stars. In this case the resolvable nebulæ, if composed of separate stars, must be made up of very small ones. These theories are confirmed by the fact that patches of nebulosity very frequently form elongated wisps, which very often lie in the same direction as streams of stars in their neighbourhood, thus giving evidence that they are really in proximity. This applies equally to those wisps of the Milky Way visible to the naked eye, as to those disclosed by an opera-glass or a telescope.

Besides the surveys of the heavens already made with the naked eye, and by Argelander and others, Proctor points out (*Knowledge*, vol. vii. p. 168) that 'we want surveys of the heavens made with many other powers—as with a 1½-inch telescope, a 4-inch telescope (this I have partly tried, and I know the results of a full survey would be most valuable), with a 6-inch telescope, and with a 12-inch telescope; the more interesting regions disclosed by such surveys as these being then examined with the

highest telescopic powers that can be brought to bear upon them. It is essential that the southern hemisphere should be at least as carefully surveyed as the northern; for no one who has ever looked at the southern skies can fail to recognise that they are much more variegated, and therefore much more likely to be instructive in regard to celestial architecture, than the skies north of the equator.

'Lastly, these surveys should be accompanied by widely extended study of proper motions; by the application of the spectroscope to determine the constitution of stars in different parts of the heavens, and their movements of recession and approach.

'I venture to predict that as this work proceeds, for I am sure it will in due time be undertaken, science will be compelled to give up more and more the idea of uniformity of structure within the stellar universe, recognising a grandeur and complexity in its architecture, a variety, yet harmony, in its movements, and a significance in its amazing vitality, akin to but of a far higher order than the corresponding qualities within the planetary system.'

It will be seen that there are three principal modes of investigation required: (1) Observations with the naked eye or with small instruments; (2) observations with large instruments; and (3) calculation and discussion of observations already made, especially those on parallax and proper motions.

T. W. B.

CHAPTER XI.[1]

THE ZODIACAL LIGHT.

THE Zodiacal Light is a cone-shaped, or lenticular, beam of light which makes its appearance at certain times of the year, above the eastern horizon in the mornings before dawn has commenced, and above the western horizon after sunset in the evening, remaining visible long after twilight has ceased.

It is a phenomenon which does not require instruments for its observation, although assistance may be derived from them in a more exhaustive study of its exact position in the heavens, and the nature of the light which it emits.

The phenomenon is generally supposed to be due to a sort of nebulous envelope surrounding the Sun, and densest in or near the ecliptic—hence the name Zodiacal Light. It is assumed that the light is due to finely divided matter of some sort, shining either by reflected sunlight or possessing inherent light due to electrical or chemical action. It is also supposed that this nebulous matter is concentrated towards the Sun, and gradually grows rarer as its distance from the Sun increases, but extending beyond the Earth's orbit. A theory has, however, been

[1] This chapter is founded on practical suggestions offered by Mr. T. W. Backhouse, supplemented by the exhaustive collections of Mr. Arthur Searle.

advanced that the nebulosity is equally dense at all distances from the Sun, and that its increased brightness near the Sun is simply owing to its greater illumination; but this theory seems very improbable, and has not met with much support. The hypothesis that the Zodiacal Light is a terrestrial appendage, and not a solar one, has been shown by Proctor to be inconsistent with its appearance and position as seen in northern latitudes. There have been numerous observations of the Zodiacal Light recorded by experienced observers of celestial phenomena, but Schmidt has remarked that all the observations from 1855 to 1868 seem to add little or nothing to our knowledge of the position and true character of this mysterious phenomenon.

Amongst the first regular observations of the Zodiacal Light were those made by Commander Jones in the years 1853–55, while engaged on the United States Japan expedition, and to this able observer seems to be due the discovery that the apparent position of the light varies with the inclination of the ecliptic to the horizon.

The Zodiacal Cone, as it may be called, to distinguish it from other allied phenomena which have been termed the Zodiacal Band and the Gegenschein, is, according to Lewis, the only part of the phenomena which varies in appearance. It has often been described in popular works on astronomy, but is frequently misrepresented, especially in pictures intended to represent its appearance, which generally show it too bright and better defined than it is usually seen, at least in northern latitudes. The apparent brightness of the Zodiacal Light depends upon the time of year. It is most visible when the ecliptic makes the greatest angle with the horizon. To an observer in the northern hemisphere it is, therefore, best seen in the *evenings*, from the

middle of February to the middle of March, and in the *mornings* in or about October. (In the southern hemisphere the times differ by half a year from these.)

As beginners often find a difficulty in perceiving the Zodiacal Light from not knowing what to look for, and when to look for it, observations may be most suitably commenced at the above-mentioned periods of the year; but in order that these observations should have any real scientific value, they should be conducted in a systematic manner, the position of the axis or else of the boundaries of the light with reference to neighbouring stars being accurately determined, and the times of observation carefully noted. A clear evening or morning should be chosen, and the Moon absent, although feeble moonlight does not overpower it. And the last rays of twilight must have died away, or the observation be made before the commencement of dawn, if the inexperienced eye is to detect it as a distinct object. Its appearance then is that of a spindle-shaped light rising from the horizon, at a steep inclination to that plane. Its light is always greatest near the centre, and fades away very gradually towards the edges. According to Lewis, the axis of greatest brightness lies south of the axis of symmetry. The lower edge of the cone is generally more distinctly defined than the upper. Jones found that the light was deficient on the south side when seen from a position north of the ecliptic, and on the north side when seen from the south. This may be explained by atmospheric absorption acting more effectively in reducing the light on the side of the cone nearest to the horizon. The Zodiacal Cone is brightest near the Sun, but still sufficiently bright at a distance of 50° or 60° from him to be quite conspicuous to a trained eye. The apex of the light occasionally reaches to a distance of 100° from the Sun.

In the brightest visible part of it, it is several times as bright as the brightest part of the Milky Way visible in northern latitudes. On two occasions—February 12, 1877, and February 21, 1879—Lewis found it sufficiently bright to cast a shadow (!). On the latter night the ground was covered with snow, on which distinct shadows were visible. In the tropics, where the twilight is very short, the light appears much brighter, and is plainly visible almost every clear night. Jones's observations seem to show an elongation of the Zodiacal Light towards the east as the evening advances; but Searle points out that this apparent extension may be really due to an effect of contrast caused by an increase in the darkness of the sky for a long time after twilight has ended, and possibly also by an increase in the sensitiveness of the observer's eye, which may take place more gradually than is generally supposed.

Many people, on first seeing the phenomenon, mistake it for a continuance of twilight from its want of definiteness, but it may easily be distinguished by the fact that the fading twilight extends along the horizon a long way, and only reaches up a short distance in the sky; whereas the Zodiacal Light, at the periods of the year named, makes an angle of about 60° with the horizon in our latitude, and is comparatively narrow.

As has been said, the Zodiacal Light extends beyond the Earth's orbit, and should, by inference, suffuse the whole sky. Its extension throughout the zodiac has actually been noticed by many observers forming a zone of faint light, considerably fainter than the Zodiacal Cone itself, and which has been called the Zodiacal Band. This band has been observed by Backhouse, Brorsen, Lewis, and Schmidt. Backhouse can always see it under fairly favourable atmospheric conditions, stretching right across the sky except

where it crosses the Milky Way; it is therefore best observed when the Milky Way is on or near the horizon. He finds that it cannot be clearly observed when at all near the horizon, as the light of the sky increases downwards, and so extinguishes the dark space that otherwise would be visible below the Zodiacal Band. He can thus never see it in the southern portion of the zodiac, owing to its low altitude in the North of England. It would seem that keen sight is necessary to observe this very faint band well, as, according to Lewis, it is one of the faintest objects in the heavens, being considerably fainter than the faintest portions of the Milky Way. Lewis, who has seen it well, has sight sufficiently acute to enable him to frequently see 12 stars in the Pleiades with the naked eye. He finds that the band is somewhat brighter in the centre than at the edges. As might be expected, this faint band of light disappears on moonlight nights, although its visibility in the presence of the Moon has, it is said, been recorded on two or three occasions! Although the Zodiacal Band, on the whole, becomes feebler as its observed distance from the Sun increases, yet in the region opposite the Sun its brightness revives again in a marked degree. This brighter region was named by Brorsen, who discovered it, the *Gegenschein*; in English, the Counter Glow. The Gegenschein has been always found to lie within 2° or 3° of a point in the heavens 180° from the Sun. Though brighter than the Zodiacal Band, it is always much fainter than any of the brighter parts of the Milky Way. The brighter portion of this patch of light is roughly circular, and about 7° in diameter, though it has occasionally been noticed as apparently elliptical, with its major axis parallel to the ecliptic. It was independently discovered by Backhouse in 1875, and again in 1883 by Barnard. Observations

by Searle 1878–84 show a marked tendency to place the Gegenschein in north latitude. This result is confirmed by Lewis, who finds that it always lies about 2° ± north of the ecliptic, not a single observation giving its position south of that line. Heis also concurs in placing it north of the ecliptic. Searle thinks the fact may be accounted for by the atmospheric absorption, but the absence of any southern observations of the Gegenschein renders it difficult to decide this point. It is not easy to frame any hypothesis which will satisfactorily account for the appearance of the Gegenschein, but on the meteoric theory it could be accounted for by assuming 'such a law for the phases of the meteors that their brightness would rapidly increase as they approached opposition.'

The Zodiacal Light, like all faint indefinite objects, is seen very differently by different people, as it requires practice to detect its fainter parts, and eyes vary much in sensitiveness. Backhouse, commencing astronomical observations in 1857, failed to see it till 1861, and not till 1868 could he see the Zodiacal Band, nor till 1875 the Gegenschein, which he independently discovered in that year.

Some observers recommend, in observing the faint parts of the light, screening the eyes from all light except that from the rather small portion of the sky to be examined, but Backhouse finds this unnecessary. It will, however, be necessary to shut out all bright light, and the less luminous portions cannot be well seen in a town where there is smoke illumined by gaslight, or where the electric light is in use, as in the city of Boston (U.S.A.), where Searle finds it no longer possible to observe the Zodiacal Light satisfactorily.

From the fact that the brightest part of the light is

seen only near the horizon, and that most of it is very faint, its appearance is greatly affected by the varying transparency of the atmosphere. On this account it is very difficult to say whether its light varies from time to time or whether it is always the same. Many observers are of opinion that it varies greatly, but probably the apparent variations are chiefly due to atmospheric changes. Also when persons see the Zodiacal Light brighter than they have ever seen it before, they are apt to conclude that its brightness has increased, whereas, in reality, their own eyes may, from practice, have become more sensitive to its faint light. Backhouse states that he has never noticed any changes of brightness more than can thus be accounted for and by atmospheric variations. He thinks, however, that the Gegenschein probably varies in form and size.

Photometric comparisons of the light with that of the Milky Way are perhaps necessary to determine whether it really varies in brightness or dimensions. Some observers have noticed momentary movements or flashings in it; but probably these are only subjective phenomena.

What its substance really is still remains to be proved. It is practically a feeble extension of the solar corona, although its nature may be very different from that portion of the corona visible in total eclipses of the Sun, and which must exist under such different conditions of temperature, pressure, &c. Its origin may not necessarily be the same, but it seems that no line can be drawn where one ends and the other begins. Some think that the Zodiacal Light is simply an aggregation of the myriads of meteors which undoubtedly exist in the solar system; but if it was nothing more than this there would be no reason for its being so much denser in the plane of the ecliptic than elsewhere; we should also expect variations in its form and brightness

greater than have actually been observed. On the nebular hypothesis, it may possibly be the remains of the original nebula of the solar system that have not been condensed into planets. We can hardly doubt, however, that meteors or remains of comets must form part of it. Searle suggests that a portion at least of the light may be due to sunlight reflected from very minute planets, which may possibly accompany the asteroids in large numbers; and if we suppose a number of meteoric particles diffused through the solar system, and reflecting light irregularly, it may be shown mathematically that an appearance resembling the Zodiacal Light, with an indefinite vertex, would be the result.

Exact observations of the position of the axis would be very useful to assist us in determining its real situation in the solar system, and whether this is always exactly the same. Numerous observations for this purpose have been made by observing the edges, and taking a point midway between these as being the axial line. Backhouse, however, thinks it better, as well as easier, to observe the position of the axis directly; for in England the southern border is always more definite than the northern. Observations show that the axis is not precisely on the ecliptic. Backhouse, from his own observations, finds the probable position of the ascending node somewhere about longitude 35°, with an inclination of about 1°·7. Houzeau found, from a discussion of 58 observations by various observers, that the longitude of the ascending node is about 2°, with an inclination of about 4°. Cassini was of opinion that the axis of the Zodiacal Light lies in the plane of the Sun's equator, and this idea is partly supported by observation; it also seems probable on theoretical grounds, 'for it is possible that the rotation of the Sun indicates the fundamental plane of the solar system, if we accept the ordinary

nebular hypothesis for its formation, more correctly than can be done by the revolution of the known planets' (Searle). Owing, however, to the required delicacy of the observations, it can hardly, perhaps, be considered proved that there is any fixed inclination. To determine this it would be well to have observations in other parts of the world, as the atmospheric absorption towards the horizon will necessarily shift the axis more or less towards the north, as seen in the northern hemisphere. Therefore, accurate observations in the southern hemisphere, and still better in tropical regions, are very desirable.

Angström stated that he had seen the auroral line in the spectrum of the Zodiacal Light; but it is now considered more probable there was feeble auroral light in the sky at the time of observation which he did not notice, as other observers have failed to detect any line. During the aurora of May 2, 1877, the Zodiacal Light was also visible, and Lewis found that the Zodiacal Cone gave 'a faint, short, continuous spectrum, brighest near its least refrangible end.' 'It was very faint throughout, and could only be seen through a wide slit,' too wide to permit the Fraunhofer lines to appear. He thinks that his spectroscopic observations point to reflected sunlight as the source of the light of the Zodiacal Cone, and this is the generally accepted opinion. The aurora gave a spectrum much longer, 'though of about the same pale greenish colour.'

Searle finds from his own observations that there exists 'a faint permanent band of light,' about 2° or 3° in width, closely south of β and η Virginis, nearly parallel to these stars, and reaching as far as α Virginis. It appears, however, that there is a slight relative abundance of *Durchmusterung* stars all along the ecliptic in this region, which may possibly, he thinks, account for the faint band referred

to. Whether this applies to the fainter telescopic stars must be left, perhaps, to photography to decide.

Geelmuyden remarks that if we suppose the Zodiacal Light to bear the same relation to the general meteoric matter of the solar system that the comets of short period bear to comets in general, there should be some relation between the plane of Jupiter's orbit and that of the Zodiacal Light, and he remarks that such a coincidence actually exists, for 'the most northerly point of Jupiter's orbit has the heliocentric longitude 188°, or with 60° east elongation, 178°; and for matter in the same plane, but nearer the Sun, the approximation to coincidence with 160° is stil greater.'

CHAPTER XII.

METEORS.

EQUIPMENT.—The observation of large meteors and ordinary shooting-stars, and of their points of radiation, forms a branch of astronomy which not only opens up a wide field of important research, but one which embraces so many attractive features that it is surprising more observers do not apply themselves to sift the anomalous facts suggested by past observations. No expensive or elaborate instruments are required in the recording of meteors, a celestial globe, or series of specially constructed star-charts, being all that is required. These, coupled with a good knowledge of the constellations, a quick eye, and a large amount of patience on the part of the observer, will soon enable him to secure a large store of interesting data.

WHAT TO OBSERVE.—The two essential points in observations of meteors are the exact *directions* of their paths and the *durations* of their visible trajectories. It is of extreme importance that these elements be invariably recorded with the utmost attainable accuracy. Unless this is done the results will assume a very complicated character, and errors will be introduced which it will be found impossible to eliminate. The lines of flight must be exactly repro-

duced on the globe or chart, so that the radiant may be found within a small limit of error, and the duration becomes necessary in any investigation relatively to the orbit.

The work of observers in this branch consists in watching regularly for the appearance of meteors, and in recording their visible courses and characters as they are successively projected on the background of stars. In order to be as complete as possible, the watch for these bodies should be maintained every clear night when the Moon is not brilliant, for there is no date in the year barren of meteoric displays. Some observers only look out for the chief periodical showers, and thus miss the host of minor systems occurring at other seasons. Each path as observed is marked upon the globe or chart, and the meteor catalogued under the following heads :—

(1) Date ; (2) hour ; (3) magnitude ; (4) R.A. and dec. of point of appearance ; (5) R.A. and dec. of point of disappearance ; (6) length of path ; (7) duration ; (8) characteristic aspect, such as streak, train, or other feature ; (9) probable radiant point.

After a night's observation, when the observer has recorded a fair number of meteors, he carefully analyses them for the purpose of deriving their radiant points. Prolonging the paths in the backward line of motion, he finds several which mutually intersect at a focus, and these he regards as belonging to one and the same family. But in order to avoid the risk of adopting radiants which result from the mere chance convergence of tracks, it is also necessary to consider the visible peculiarities of the individual meteors to some extent. Those belonging to the same radiant usually show a great resemblance in velocity, in streaks or trains, &c. The length of path relatively to the assumed

place of the radiant at the hour of observation is also a useful adjunct in determining the true radiant, for such centres near the zenith give swift diving meteors of short trajectories, whereas those at low altitudes display slower meteors traversing inordinately long flights. The Perseids of August 10 vary considerably as the radiant rises. Between $9^{h.}$ and $10^{h.}$ the brighter meteors will average about 30°; from $10^{h.}$ to $11^{h.}$ about 20°; from $11^{h.}$ to $12^{h.}$ about 14°; and in the morning hours, with a high radiant, not more than 10° or 12°. These differences are the effects of perspective, and they ought never to be disregarded by observers who appreciate the difficulties of obtaining accurate results without accepting all the trustworthy materials available to that end. In the case of very active showers the necessity for extreme caution is not so urgent, as a few meteors wrongly attributed will not materially influence the results. It is more with regard to the feeble systems, of which enormous numbers apparently exist, that great care is so essential.

Some showers only furnish about one meteor in three or four hours, and there are many others still more attenuated. Systems of this character apparently exist in great numbers, especially in the E. region of the heavens, towards which the Earth is moving in her orbit. At the end of July 1878 I found fifty-five separate radiants in activity; and on August 10, when a great number of observations have accumulated, still more are capable of determination. The necessity, therefore, of accuracy in such work is perfectly obvious.

Number of Radiants.—About 3,000 radiants have been given in various catalogues as follows (the letter R. signifies reduced from other observations; Ob., observed and reduced; OR., partially observed and reduced):—

Backhouse	56 Ob.	Konkoly	91 OR.
Bártfay	17 R.	Kobold	8 R.
Corder	130 Ob.	Kövesligethy	35 R.
Denning	820 Ob.	Schiaparelli (R.) and Zezioli (Ob.)	189
Denning	605 R.	Schmidt	152 Ob.
Gruber	30 R.	Sawyer	125 Ob.
Heis	173 OR.	Tupman	183 Ob.
Heis	39 R.	Weiss	102 R.
Herschel, A. S.	87 OR.		
Greg and Herschel	151 OR.		

These reach 2,993, but many of them are duplicates, and the probable aggregate of definite showers at present known does not exceed 500. Of the total number included in the above catalogues, about 850 are for the six months, January to June, and 2,143 from July to December. They were derived from the registered paths of more than 82,000 shooting-stars.

Identity of Meteoric and Cometic Orbits.—The orbits of meteors are supposed to be similar to comets, and the former bodies really comprise the *débris* or waste-material of the latter. In four cases a very precise and, indeed, conclusive identity of orbit has been discovered between comets and well-known meteor streams as follows :—

Comet I. 1861 = Lyrids of April 19–20.
Comet III. 1862 = Perseids of August 9–11.
Comet I. 1866 = Leonids of November 12–14.
Comet III. 1852 = Andromedes of November 27.

These instances appear to be the only ones of absolutely certain character. In the cases of the Lyrids and Perseids, the radiant point advances amongst the stars from night to night, and it is probable that a similar tendency is apparent amongst all other streams moving in the same orbits.

Horary Period.—Meteors are much more numerous generally in autumn than in spring, and in the morning

hours the rate of apparition greatly exceeds that shown during the evening hours. From more than 6,000 meteors observed at Bristol during the years 1876–79, I found the horary number 12·6, after deducting the Perseids; but these figures include the occasional observation of showers like the Orionids and Geminids, and, moreover, relate to the last half of the year, when shooting-stars are considerably more frequent than during the first half.[1] Before midnight the hourly average is 9·4, and 15·7 in the morning. Olbers formerly estimated the horary number as 5 or 6, and Quetelet as 8. Coulvier, Gravier, and Saigey confirmed Olbers, as their results gave 5·7; but Schmidt derived a lower rate from his observations, viz. 4·3. Colonel Tupman's records of 3,798 meteors seen in 1869–71 show an hourly rate of about 19, deducting the observations from July 27 to August 12, but his results were nearly all obtained A.M. Giuseppe Zezioli's at Bergamo, Italy, in 1867–70, are also much higher than most observers, owing probably to an acute eye and a very clear atmosphere.

The discrepancies in these results are doubtless more apparent than real, and have their origin in differences of method, eyesight, atmosphere, place and hours of observation. This part of the subject will repay further investigation. During the ordinary process of registering paths, observers should invariably retain notes as to the number seen each hour. The maximum rate of apparition appears to be attained about 3 A.M., so that the clustering of visible meteor streams would seem to be concentrated at about 135° W. of the Sun.

RADIANTS OF LONG DURATION.—But perhaps the most singular anomaly of observation is that regarding the long duration of certain radiant points and their stationary posi-

[1] *Astronomical Register*, Feb. 1884, p. 43.

tion in the heavens. On the theory that meteor streams pursue cometary orbits, it is impossible that individual showers can maintain visible activity from the same points longer than one or two nights, except in exceptional cases; and yet in many well-defined instances it appears conclusive that they are continued for several months together. The fact suggests such an obvious departure from the teachings of theory that it ought to be subjected to such rigorous tests as the most accurate and prolonged observation can possible apply. The confirmation of this singularity will indeed only become feasible by the determination of radiant points with the utmost precision and certainty, and the explanation of it has been referred to the existence of immense streams of meteors coursing through space with enormous velocities, and owning no sort of allegiance to our Sun or rendered amenable to his attractive influence.

Telescopic Meteors.—Apart from the ordinary shooting-stars, which the nocturnal sky invariably yields to the persevering observer, meteoric astronomy furnishes us with a varied host of included phenomena. Amongst these may be mentioned telescopic meteors, bolides and fireballs, detonating or aerolitic meteors, and either stonefalls or ironfalls. As to telescopic meteors, they are mostly seen during the process of sweeping the heavens for comets or new nebulæ by those who employ low powers and large fields of view for their especial work. From my own observations in this line, I computed that the relative number of meteors, visible with telescopic power, to ordinary naked-eye meteors was in the proportion of about forty to one, and the comparative slowness of motion and brevity of path led me to infer that the former class are situated at great distances from the Earth's surface. Astronomers engaged in comet-seeking should systemati-

cally record the number of telescopic meteors seen and the intervals of time employed in observation; also the path-directions of as many as possible. It would be interesting to learn whether these more remote shooting-stars belong to the identical systems which supply ordinary meteors and fireballs. It is quite possible, however, that there are rich showers of minute meteors of a character quite distinct from such systems as have been already recognised. The corpuscles of certain meteor groups may be more readily combustible than others, and rendered incandescent at a distance far beyond what has been assigned as the limits of our atmosphere.

Bolides and Fireballs.—As to bolides and fireballs, they represent the largest specimens of ordinary meteors, and are interspersed with them in common orbits such as the Perseids, Leonids, and Taurids. Some systems, however, unquestionably yield a larger proportion of fireballs than others, and it is possible in certain instances that these bodies are more or less isolated or sporadic in character. But it is usually found that the dates and positions of fireballs agree with showers of ordinary type, whence their identity of origin is very justly inferred. Detonating and aerolitic fireballs may also be another form of the same phenomena, though allied to systems of which the fragments are composed of very hard and compact materials—such, perhaps, as the well-known shower of Taurids on November 19–23, which has discharged many fine meteors of detonating character. Stonefalls, and the still more rare ironfalls which are synonymous with meteorites, though furnishing some extremely interesting facts as to the physical nature of the bodies which reach our Earth from interplanetary space, scarcely come within the aim of our description, as they are of very exceptional character.

In all cases, however, observers should preserve records of the essential features of such phenomena. The paths of meteors either large or small, the lines of phosphorescence generated as the result of concussion with the atmosphere, the offcome of sparks from the nucleus, the occurrence of curved paths, of intermittent brilliancy or irregular motion, &c., deserve mention whenever observed. It matters not what may be the particular form of meteoric exhibition, the appreciative observer will not be slow to record its more salient features, omitting all exaggerated and fanciful description while retaining the less impressive, though far more significant, facts of the display.

Projection of Meteor Paths.—In recording meteor paths I have found it conducive to accuracy to project a perfectly straight wand, held in the hand for the purpose, upon the track of each meteor as seen; then, carefully noting the direction and position relatively to adjacent stars, the path may be reproduced upon the globe or chart with a considerable degree of precision. Relying upon the eye alone, we receive, immediately upon the complete disappearance of a meteor, impressions which are erroneous. The wand, however, being projected on the line of flight, often leads us to results of instrumental exactness, and does away with the supplementary impressions of direction often induced when the eye has no such guide. Indeed, I have found its simple assistance invaluable: it has often enabled radiant points of very swift meteors to be fixed within one degree of probable error. When a person has become habituated to this work, and employs every precaution found necessary from experience, it is found that the backward prolongation of the paths intersect at a point, and exhibit nothing of that diffuseness so apparent in results

based on inadequate methods or affected by errors inseparable from non-practised eyes.

Duration of Meteors.—As to the durations of individual meteors, it is extremely difficult to gauge such very brief intervals with that precision so much desired. In the case of slow-moving meteors it is possible to estimate the time tolerably well; but the swifter courses, limited to a small fraction of a second, obviously require extreme care, and it must be admitted there is no safe method of measuring such transient intervals. I found it a useful expedient to practise myself by frequent estimation of arrow flights and comparisons with a seconds watch after each trial. Standing with the line of vision at right angles to that of a friend discharging arrows from a bow to distances between about 50 and 200 yards, and varying the elevation as much as possible, I have, by a method of counting, estimated the times of flight, and tested them with the times registered by the watch. Repeating these experiments occasionally, an observer will be enabled to judge intervals of from about one to five seconds with a very near approach to the truth. In my own case the average error is less than the fifth of a second, and this, though still merely approximate, is an advance upon the haphazard manner of guessing the durations, which has rendered this very important detail of observation so very uncertain in many cases, either from the want of method or from the surprise occasioned by the suddenness of meteoric apparitions.

B. A. Instructions.—Observers will find a most valuable and exhaustive *précis* of suggestions and instructions with reference to the recording of meteors in the 'Report of the British Association Committee on Luminous Meteors for 1878,' pp. 114-21. It is drawn up by Prof. Alexander Herschel, F.R.S., and embodies a large amount of useful

information to those who may have an intention of making this branch a specialty.

CATALOGUE.—The latest general catalogue of meteor showers is by Mr. R. P. Greg (for many years Professor Herschel's coadjutor in this attractive field) in the British Association Report for 1876. A chart accompanies this, but the wholesale system of averaging radiants situated near together has in part destroyed its utility, for we frequently find two or three showers grouped into one system. Moreover, since the publication of this catalogue a vast number of fresh radiants has been ascertained, and a new comprehensive summary of all such positions has become a great want. The uncertainty attached to the visible durations of certain shower-radiants has rendered it advisable to await the solution of the difficulty before rearranging all the results. If showers are to be strictly confined to a duration of two or three nights there must be considerably more than 10,000 of such streams visible during the year; and when we remember that enormous numbers of telescopic meteors are also visible with their more thickly strewn radiants, the opinion is induced that the radiant points of all the included forms of meteoric display *are as numerous as the stars in the sky*. But if the further observation of long-continued showers leads to the definite acceptance that sporadic streams exist in large numbers (forming a distinct class to the cometary streams whose orbits agree with the conic sections), and are visible month after month with a persistent stationary radiant, then the known list of showers will be cut down to a number with which we may confidently hope to grapple with successful results. This field of research, so wide in its reach and complex in its details, is even now comparatively unexplored, and we may

expect some important issues will be the result of investigations in future years.

A List of the chief Meteor Showers visible during the Year.

Epoch of chief display	Position of radiant point	Approximate star	Notes
	R.A. Dec. ° °		
January 2–3 . .	232+49	β Bootis	A rich annual shower
January 4–20 . .	295+53	χ Cygni	Observed in 1877 by Denning
January 18–28 .	233+31	θ Coronæ	Observed in 1868 by Zezioli
Jan.–Feb. . . .	145+ 6	o Leonis	Also in November and December
February 20 . .	181+34	12 Can. Ven.	Also in Jan., meteors very swift
Feb.–March . .	177+13	β Leonis	Many large meteors
March–April . .	268+25	μ Herculis	Meteors swift, with streaks
April 9–12 . . .	249+51	r Draconis	Also at 184°+59° and 212°+65°
April 19–20 . .	275+34	α Lyræ	A notable shower = Comet I 1861
April–May . .	240+25	ε Coronæ	Also in June and July
April–May . .	208− 6	κ Libræ	Meteors slow, with long paths
April 29–May 2 .	326− 2	α Aquarii	Fine shower obs. by Tupman 1870–71
May 30	330+28	μ Pegasi	Meteors swift, with streaks
June 10–28 . .	335+57	δ Cephei	Meteors swift
June 4–13 . . .	312+60	α Cephei	Meteors swift, with streaks
June 13–20 . .	302+24	Vulpecula	Meteors rather swift
July	305− 9	α Capricorni	Also in June, meteors very slow
July 27–29. . .	341−13	δ Aquarii	Active shower, also in Aug. and Sep.
July–August . .	7+37	μ Andromedæ	Meteors swift, with streaks
July 23–25. . .	46+45	α–β Persei	Rich shower = Comet of 1764?
July to October.	30+36	β Trianguli	Shower very long continued
August 9–11 . .	43+56	η Persei	A very fine annual display
August 21–23 .	291+60	o Draconis	Well observed in 1879
August 21–25 .	70+50	α Aurigæ	Meteors very swift, with streaks
September 1 . .	305+54	α Cygni	Well-defined shower N. of α Cygni
September 4–17 .	60+36	ε Persei	Rich shower, many fine meteors
September 21–22	74+44	α Aurigæ	Well observed in 1879 and 1884
October 17–20 .	90+15	ν Orionis	Notable shower recurring annually
October. . . .	29+ 8	ξ Arietis	Meteors very slow and small
Oct. 31–Nov. 4 .	43+22	ε Arietis	Meteors slow, often very brilliant
Oct.–Nov. . . .	108+23	δ Geminorum	Meteors swift, with streaks
Oct. 21–Nov. 30.	62+21	ε Tauri	Meteors slow, often very brilliant
November 13–14.	149+23	γ Leonis	Rich periodical display = Comet I 1866
November 27. .	25+43	γ Andromedæ	Rich periodical display = Biela's comet
Nov. 27–Dec. 12.	80+23	ζ Tauri	Meteors very slow and bright
December 9–12 .	107+33	α Geminorum	Active shower recurring annually

CHAPTER XIII.

THE AURORA.

THE Aurora doubtless more strictly belongs to the domain of meteorology than to that of astronomy; but when the frequent opportunities of the astronomer to observe the phenomenon, and its possible influence in some form on the celestial bodies, are considered, it may not be out of place to introduce a short notice of it into this volume.

HISTORY.—The early history of the Aurora is too long to do more than mention here. We have accounts of Auroras of early date from the Chinese, Hindoos, Greeks, Romans, and other nations of antiquity, who even distinguished its principal features by appropriate names. Something very much like it is described in the Second Book of Maccabees, chapter v., verses 1–4 (B.C. about 176 years) A complete and scientific early history of it is to be found in De Mairan's 'Traité Physique et Historique de l'Aurore Boreale,' Paris, 1754. A later condensed one, bringing the subject up to present times, is an article 'Aurora Polaris' in the 'Encyclopædia Britannica,' ninth edition, part ix., pp. 90–99. An intending observer cannot do better than adopt one or both of these for preliminary study.

APPEARANCE.—Its appearance also we need not long dwell upon. The general appearance of the Aurora has been times and oft described by scientists and poets in terms so variable that the accounts hardly ever present the same features. Perhaps two of the most characteristic descrip

tions are by Weyprecht in Julius Payer's 'New Lands within the Arctic Circle,' pp. 328–335, and by Longfellow in his preface to 'The Children of the Lord's Supper,' the last being a truly poetic one.

FEATURES.—The main features of an Auroral display, some or all of which may appear, may be summed up as follows: [1]—

1. The glow either entire or in patches, and yellow, red, green, or white, as the case may be, or with these colours mingled.

2. An arc or arcs, sometimes double vertically, or multiple horizontally, forming a low bow or bows upon the horizon.

3. An evenly dark space between the arc and the horizon, considerably darker than the sky above the bow.

4. Bright rays, streamers, or coruscations, continuous or in groups, shooting from above, and sometimes below, the arc.

5. Transverse, horizontal (or nearly so) streamers, or rays, crossing those thrown out from the arc.

6. Apart from the arc, streamers, or rays, detached or in groups, horizontal or vertical, which latter, springing from E. and W., sometimes form arches uniting in a luminous point or ring called the corona (an effect of perspective).

7. Phosphorescent-looking patches or clouds often accompanying or preceding an Auroral display.

EXAMINATION.—The obvious duty of an observer is to accurately take note of all or any of the above-described features, to sketch them if he can, and, as far as possible, to fix their true position in the sky, this being usually more

[1] Some good coloured illustrations of typical forms of Auroræ, by Professor C. Piazzi Smyth, Astronomer Royal for Scotland, will be found in the *Edinburgh Astronomical Observations*, vol. xiv. 1870–77, plates 5–7.

or less in the magnetic N., NE., and NW. This may be absolutely done by means of the 'Aurora theodolite,' as it has been called, consisting of a small alt-azimuth telescope (preferably of metal, but it may also be of wood and cardboard), as is the one figured (p. 314), fitted with horizontal and vertical circles of 360°. A pair of thick cross wires replace the ordinary object-glass, and the eye end carries a cap with a small mirror set at right angles, in which the wires are reflected. The tubes carrying the wires and the eye-end cap respectively are made to revolve, and are divided on their edges into degrees like a position-micrometer. A compass in the base of the instrument enables it to be set on the magnetic meridian (from which the readings are taken), and a level and plummet are used for vertical and horizontal adjustment. The eye-end cap with mirror may be changed for other apparatus.

With this instrument the altitudes, widths, and bearings of arcs or arches, and the positions, angles, and length of beams, streamers, and other parts of the Aurora may be explored and registered.

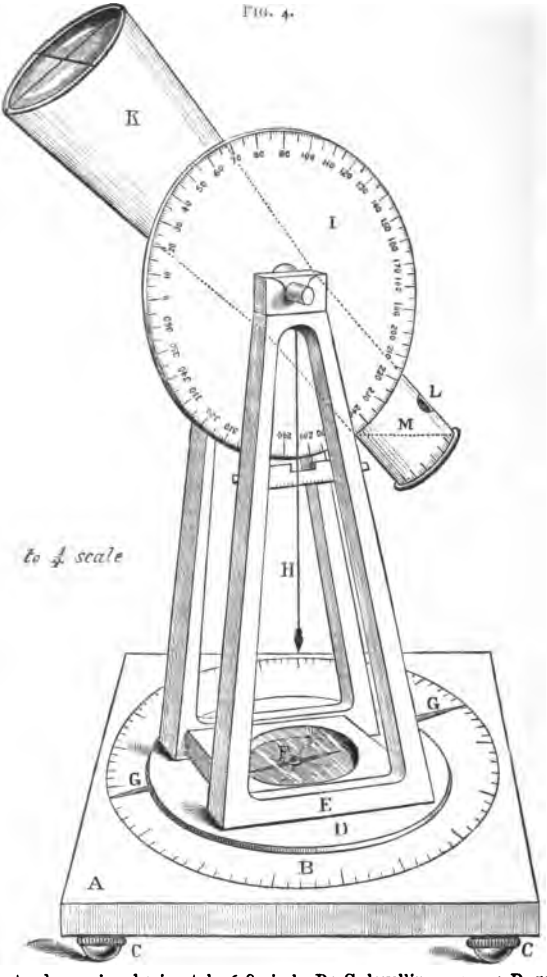
If such an instrument is not at hand, an ordinary sextant, an equatorial telescope, a clinometer, or, failing these, eye-estimated observations should be adopted.

The phenomena to be examined and noted are mainly these:—

1. The time and duration of the Aurora.
2. The extent, direction, and colour of the glow.
3. The position, width, and height of the arc or arcs.
4. The positions, angles, character, and bearings of the arches, beams, or rays.
5. Any flickering and changes which occur in the above during the continuance of the Aurora.

Other Matters to be examined.—During the time of display the wind direction, barometric pressure, and tempera-

FIG. 4.



A, stand carrying horizontal 360° circle, B; C, levelling screws; D, revolving table carrying E, telescope stand, and F, magnetic needle; G G, pointers; H, plummet and line; I, vertical circle 360°; K, telescope; L, revolving eyepiece, carrying diagonal mirror M.